Assessment of Habitat and Streamflow Requirements For Habitat Protection, Usquepaug–Queen River, Rhode Island, 1999–2000

By DAVID S. ARMSTRONG and GENE W. PARKER

Open-File Report 02-438

In cooperation with the
RHODE ISLAND DEPARTMENT OF
ENVIRONMENTAL MANAGEMENT

Northborough, Massachusetts
2003

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
2002	**N/A**	**-**

4. TITLE AND SUBTITLE
Assessment of Habitat and Streamflow Requirements for Habitat Protection, Usquepaug-Queen River, Rhode Island, 1999-2000

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Department of the Interior 1849 C Street, NW Washington, DC 20240

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**UU**	**36**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, *Secretary*

U.S. GEOLOGICAL SURVEY
Charles G. Groat, *Director*

For additional information write to:

Chief, Massachusetts-Rhode Island District
U.S. Geological Survey
10 Bearfoot Road
Northborough, Massachusetts 01532
or visit our Web site at
http://ma.water.usgs.gov

Copies of this report can be purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286
Denver, CO 80225-0286

CONTENTS

FIGURES

TABLES

CONVERSION FACTORS, VERTICAL DATUM, AND ACRONYMS

CONVERSION FACTORS

Multiply	By	To obtain
cubic feet per second (ft^3/s)	0.02832	cubic meter per second
cubic feet per second per square mile ($ft^3/s/mi^2$)	0.01093	cubic meter per second per square kilometer
foot (ft)	0.3048	meter
foot per second (ft/s)	0.3048	meter per second
inch (in.)	2.54	centimeter
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
square feet (ft^2)	0.0929	square meter
square mile (mi^2)	259	hectare

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32$$

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32) \div 1.8$$

VERTICAL DATUM

Sea Level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

ACRONYMS

ABF	Aquatic Base Flow
FD	Fluvial Dependent
FS	Fluvial Specialist
IHA	Indicators of Hydrologic Alteration
HEC-RAS	[U.S. Army Corps of Engineers] Hydrologic Engineering Center—River Analysis System
HSPF	Hydrologic Simulation Program–Fortran
MG	Macrohabitat Generalist
RBP	[U.S. Environmental Protection Agency] Rapid Bioassessment Protocol
RIDEM	Rhode Island Department of Environmental Management
RIDFW	Rhode Island [Department of Environmental Management] Division of Fish and Wildlife
RVA	Range of Variability Approach
TNC	The Nature Conservancy
TU	Trout Unlimited
USFWS	U.S. Fish and Wildlife Service
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WPWA	Wood-Pawcatuck Watershed Association
WUSG	[Pawcatuck Watershed Partnership] Water Use Stakeholders Group

Assessment of Habitat and Streamflow Requirements for Habitat Protection, Usquepaug–Queen River, Rhode Island, 1999–2000

By David S. Armstrong *and* Gene W. Parker

ABSTRACT

The relations among stream habitat and hydrologic conditions were investigated in the Usquepaug–Queen River Basin in southern Rhode Island. Habitats were assessed at 13 sites on the mainstem and tributaries from July 1999 to September 2000. Channel types are predominantly low-gradient glides, pools, and runs that have a sand and gravel streambed and a forest or shrub riparian zone. Along the stream margins, overhanging brush, undercut banks supported by roots, and downed trees create cover; within the channel, submerged aquatic vegetation and woody debris create cover. These habitat features decrease in quality and availability with declining streamflows, and features along stream margins generally become unavailable once streamflows drop to the point at which water recedes from the stream banks. Riffles are less common, but were identified as critical habitat areas because they are among the first to exhibit habitat losses or become unavailable during low-flow periods.

Stream-temperature data were collected at eight sites during summer 2000 to indicate the suitability of those reaches for cold-water fish communities. Data indicate stream temperatures provide suitable habitat for cold-water species in the Fisherville and Locke Brook tributaries and in the mainstem Queen River downstream of the confluence with Fisherville Brook. Stream temperatures in the Usquepaug River downstream from Glen Rock Reservoir are about 6°F warmer than in the Queen River upstream from the impoundment. These warmer temperatures may make habitat in the Usquepaug River marginal for cold-water species.

Fish-community composition was determined from samples collected at seven sites on tributaries and at three sites on the mainstem Usquepaug–Queen River. Classification of the fish into habitat-use groups and comparison to target fish communities developed for the Quinebaug and Ipswich Rivers indicated that the sampled reaches of the Usquepaug–Queen River contained most of the riverine fish species that would have been expected to occur in this area.

Streamflow records from the gaging station Usquepaug River near Usquepaug were used to (1) determine streamflow requirements for habitat protection by use of the Tennant method, and (2) define a flow regime that mimics the river's natural flow regime by use of the Range of Variability Approach. The Tennant streamflow requirement, defined as 30 percent of the mean annual flow, was 0.64 cubic feet per second per square mile ($ft^3/s/mi^2$). This requirement should be considered an initial estimate because flows measured at the Usquepaug River gaging station are reduced by water withdrawals upstream from the gage. The streamflow requirements may need to be revised once a watershed-scale precipitation-runoff model of the Usquepaug River is complete and a simulation of streamflows without water withdrawals has been determined.

Streamflow requirements for habitat protection were also determined at seven riffle sites by use of the Wetted-Perimeter and R2Cross methods. Two of these sites were on the mainstem Usquepaug River, one was on the mainstem Queen River, and four were on tributaries and the headwaters of the Queen River. Median streamflow requirements for habitat protection for these sites were 0.41 $(ft^3/s)/mi^2$, determined by the Wetted-Perimeter method and 0.72 $ft^3/s/mi^2$, determined by the R2Cross method.

INTRODUCTION

During the summer, when streamflows are naturally low and the demand for water is high, water users in the Pawcatuck River Basin in southwestern Rhode Island and southeastern Connecticut are in competition for a limited supply of water. Federal, State, and local agencies as well as private citizen groups and other water-use organizations are concerned that reduced streamflows created by water withdrawals could cause a loss of aquatic habitat and reductions in habitat quality needed to support the biological integrity of the Pawcatuck River system.

In recognition that the quantity and quality of water may not be sufficient to meet all needs and interests, and that solutions to competing water needs will require cooperation among many stakeholders, the Pawcatuck Watershed Partnership Water Use Stakeholders Group (WUSG) was formed in 1997. The group consists of representatives from State and Federal environmental agencies, municipal water suppliers, universities, nonprofit environmental advocacy and conservation organizations, farmers, and other individuals. The WUSG determined that a subbasin of the Pawcatuck River Basin, the Usquepaug–Queen River Basin, could serve as a pilot area in which to focus data collection and modeling efforts. The U.S. Geological Survey (USGS) in cooperation with the Rhode Island Department of Environmental Management (RIDEM), began a habitat assessment of the Usquepaug–Queen River in June 1999. The goals of this effort were to understand aquatic-habitat availability under various streamflow conditions and to determine the streamflows needed for habitat protection in the Usquepaug–Queen River. An additional goal was to coordinate habitat assessments with an ongoing watershed-modeling project for the Usquepaug–Queen River Basin that is being developed by the USGS in cooperation with the Rhode Island Water Resources Board. Once the effects of water withdrawals on streamflows are modeled, the combined USGS efforts will provide a better understanding of the effects of water withdrawals on stream habitat.

Purpose and Scope

This report describes the stream habitats, summer water temperatures, and fish communities of the Usquepaug–Queen River, and determines streamflows necessary to maintain aquatic habitat in the Usquepaug–Queen River for the summer period. The study area includes the mainstem and tributaries of the Usquepaug–Queen River upstream from Route 2 in South Kingstown. The report describes results of assessments of stream habitat, fish communities, and stream temperature conducted in 1999 and 2000 for the Usquepaug–Queen River and its tributaries, and compares streamflow requirements determined by means of the Tennant, Wetted-Perimeter, and R2Cross methods to flow-management targets developed by means of the Range of Variability Approach (RVA). Streamflow requirements were determined at seven riffle sites: three on the mainstem Usquepaug–Queen River, and four on the Fisherville Brook and Locke Brook tributaries, and in the headwaters of the Queen River.

Description of the Study Area

The Usquepaug–Queen River, a tributary to the Pawcatuck River, is entirely within southern Rhode Island (fig. 1). The Usquepaug–Queen River Basin is bounded by the Beaver River Basin to the west, the Big River and Hunt Basins to the north, the Cocumcussoc, Annaquatucket, and Mattatuxet Coastal Basins to the East, and the Chipuxet Basin to the south. The study area includes all of the Queen River Basin and that portion of the Usquepaug River Basin between the river's origin at the outfall of Glen Rock Reservoir, in Usquepaug, RI, and the USGS streamflow-gaging station on the Usquepaug River upstream from Route 2 (station 01117420).

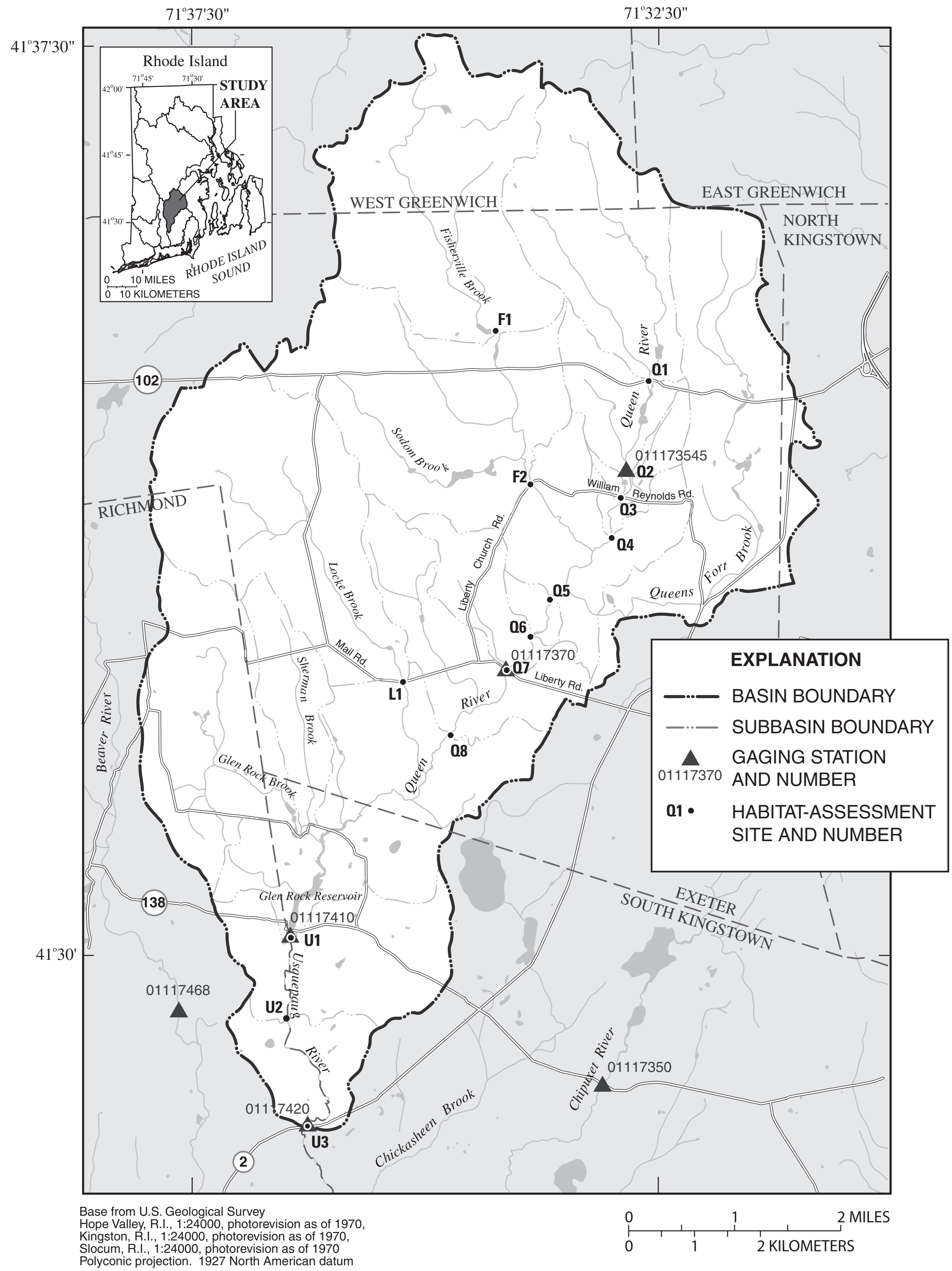

Figure 1. Location of towns, drainage network, impoundments, gaging stations, and habitat-assessment sites, Usquepaug–Queen River Basin, Rhode Island.

The gaging station is 1.2 mi upstream of the Chickasheen River and about 2.1 mi upstream from the confluence of the Usquepaug River with the Pawcatuck River. The study area is approximately 10 mi long and about 5 mi wide, and encompasses a 36 mi^2 area. Most of the study area is in Washington County, with a small area of the northern part of the basin in Kent County. The study area comprises parts of six towns, including most of the town of Exeter, and parts of the towns of Richmond, West Greenwich, East Greenwich, North Kingstown, and South Kingstown.

The drainage basin of the Usquepaug–Queen River is within the coastal lowland physiographic province of New England (Denny, 1982). The basin is characterized by low, rolling hills separated by flat valleys. Maximum relief in the river basin is about 460 ft. The Usquepaug–Queen River Valley trends northeast-southwest. Tributary valleys generally lie between northwest-trending ridges on the northwest side of the valley, and southeast-trending ridges on the southeast side of the valley. The ridges are formed by bedrock overlain by as much as 60 ft of glacial till (Dickerman and others, 1997). Glacial till generally is a compact, nonsorted mixture of sand, silt, clay, and stones. The low permeability of till and steep slopes in till areas reduce the amount of infiltration and ground-water storage and cause rapid runoff of surface water during storms. A bedrock valley beneath the Usquepaug–Queen River and Fisherville–Sodom tributary is filled with glacial stratified deposits consisting of up to 122 ft of coarse-grained deposits of sand and gravel, and fine-grained deposits of very fine sand, silt, and clay (Dickerman and others, 1997). Sand and gravel deposits form the major aquifers in the basin, and ground-water discharge from these aquifers to the streams maintains base flow between precipitation events. Tributary streams that drain areas of sand and gravel deposits, such as those along the mainstem Queen River and Fisherville Brook, tend to have higher base flow than streams draining areas of till, such as the headwaters of the Queen River.

Based on meteorological data from 1961–90 from Kingston, RI, the mean annual temperature in the Usquepaug–Queen Basin is 49.3°F. Deep ground-water temperatures in the region are about the same temperature as the mean annual temperature (Lapham, 1989). The minimum monthly-mean temperature is 27.7°F in January, and the maximum monthly-mean temperature is 70.5°F in July. Annual precipitation in southern Rhode Island averages approximately 48 in., and is distributed rather uniformly throughout the year (Johnston, 1986). The minimum monthly precipitation is about 3.3 in. in July, and the maximum monthly precipitation is about 5.3 in. in November. Average monthly precipitation in the remaining 10 months ranges between 3.7 and 4.6 in. Annual snowfall averages approximately 20 in. Average annual runoff is about 28 in. and is highest from December through May and lowest from June through November.

The USGS operates two permanent stream-gaging stations in the study area (fig. 1). The upstream gage on the Queen River at Liberty Road at Liberty (station number 01117370) has a drainage area of 19.1 mi^2, and has been in operation since 1998. The downstream gage on the Usquepaug River near Usquepaug (station number 01117420) has a drainage area of 36.1 mi^2, and has been in continual operation since 1974 (Socolow and others, 1999). The USGS has also operated two additional stream gaging stations (station numbers 011173545 and 01117410) on the Queen and Usquepaug Rivers on a temporary basis to collect hydrologic data for use in a watershed model (Socolow and others, 2001). A ground-water investigation of the basin (Dickerman and others, 1997) showed that the surface-water and ground-water divides do not coincide for part of the Queens Fort Brook subbasin and that the subsurface drainage area to the Usquepaug gaging station is about 33 mi^2. The surface drainage area of 36.1 mi^2 is used throughout this report to normalize flows by drainage area. The mean annual discharge at the Usquepaug gaging station is 76.8 ft^3/s. Discharge at these sites, however, is affected by water withdrawals upstream of the gaging stations.

Streamflows in the Usquepaug–Queen River are typically lowest in August and September. For the 1974–99 period, the medians of monthly mean flows for August and September at the Usquepaug gaging station (01117420) were about 28.4 and 22.3 ft^3/s, respectively. The daily mean discharge for water years 1999 and 2000 and the range of daily flows for the period of record are shown in fig. 2. Stream discharges were low during 1999, the first year of this study, because of drought conditions. Annual high water typically occurs between Feburary and April, though peak floods also occur in August or September because of hurricanes. Flooding is infrequent in the basin

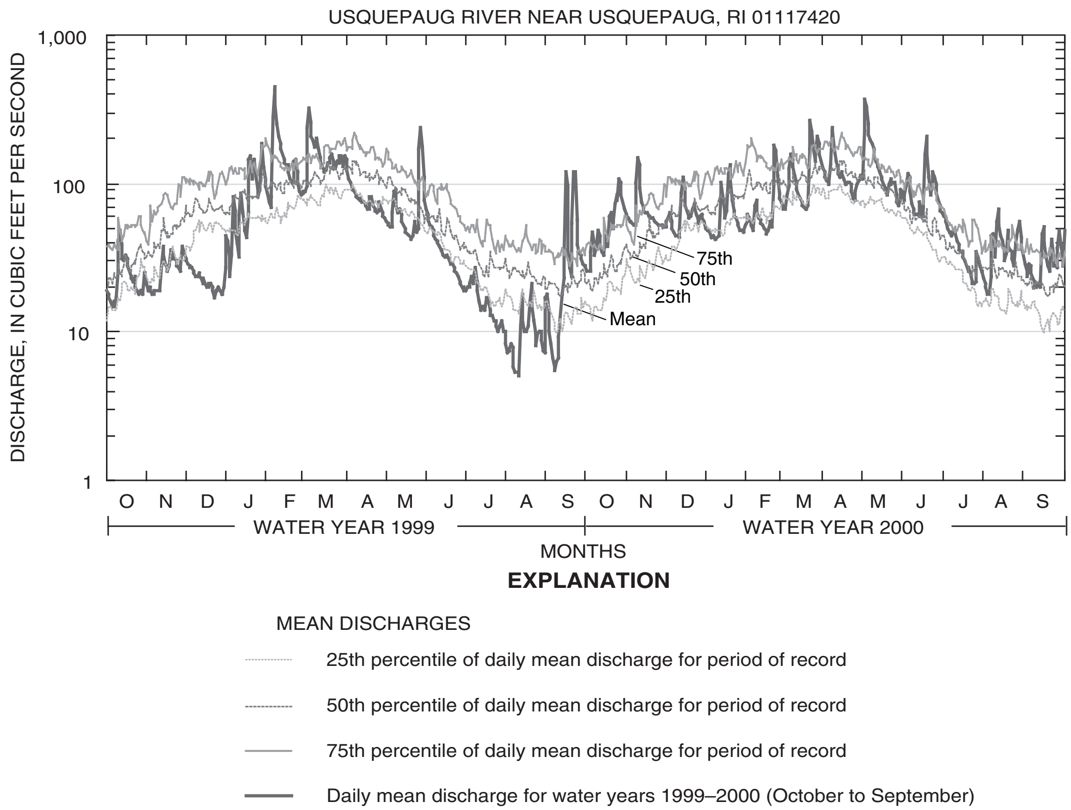

Figure 2. Daily mean discharge, water years 1999–2000, and median of daily mean discharge for the period of record for the Usquepaug River at Usquepaug gaging station (01117420), Rhode Island.

because of the large number of ponds and reservoirs, extensive wetlands, highly permeable soils, and low stream gradients (Johnston, 1986).

There are two large and a number of small impoundments in the Usquepaug–Queen River Basin. The farthest downstream of these, Glen Rock Reservoir, impounds the Queen River at Usquepaug, RI. A dam and mill have existed at or near this site since colonial times. The present dam is about 10 ft high and impounds water upstream for about a mile. Flows from the impoundment spill over a low-head dam and down a small canal near a gristmill. The second large impoundment, in the headwaters of Locke Brook, is formed by a 20-ft tall earthen dam. A small-diameter (< 6 in.) pipe at the base of the dam provides a constant flow to Locke Brook. Several small dams and ponds are located on Fisherville, Sodom, Locke, and Glen Rock Brooks, and in the Queen River headwaters.

The Usquepaug–Queen River Basin is characterized by rural land use. Approximately 90 to 95 percent of the basin is forested (Dickerman and others, 1997). The remainder of the basin is wetland, agricultural (primarily turf farming with some areas of row and vegetable crops, nurseries, and pasture), recreational (golf courses), commercial, and medium-to-low-density residential land. For most of its length, the Usquepaug–Queen River has a wide and relatively undisturbed riparian corridor; development, agriculture, or golf courses border the river in only a few locations.

The Usquepaug–Queen River is an important natural resource for southern Rhode Island, and portions of the River are considered to be among the most pristine and least disturbed rivers in the State of Rhode Island (The Nature Conservancy, 2001). Several large parcels of land in the basin have been preserved by the Rhode Island Audubon Society, The Nature Conservancy, and by private landowners. The river provides unique habitat for a diversity of fauna, including a naturally-reproducing population of brook trout, one of the greatest concentrations of freshwater mussels in Rhode Island, and several dragonfly species

that rely upon cold-water riverine habitat and are listed by the Rhode Island Natural Heritage Program as species of concern (The Nature Conservancy, 2001; Pawcatuck Watershed Partnership, 1998).

The Usquepaug–Queen River Basin is also an important source of water for agriculture, domestic water supply, and recreation. Currently, water is not imported or exported out of the basin. The predominant water withdrawals are surface-water withdrawals for agricultural and golf-course irrigation. Private water supplies are obtained from wells. There are no active centralized wastewater-treatment plants in the basin; a wastewater-treatment site at the site of the former Ladd School was shut down in 1995. Changes in land and water use related to development within the basin, the conversion of surface-water withdrawals to ground-water withdrawals, and a potential wastewater-treatment facility at the site of the former Ladd School could alter habitat, streamflow and water-quality conditions from those observed during this study.

Previous Studies

Hydrologic and hydrogeologic information for the Basin is available from earlier studies that include part or all of the Usquepaug–Queen River Basin. Kliever (1995) provides information on ground-water levels and ground-water quality, surface-water flows, and surface-water quality in the Usquepaug River Basin. Dickerman and others (1997) describe the hydrogeology, water quality, and ground-water development alternatives in the Usquepaug–Queen Basin.

Acknowledgments

The authors are grateful to the RIDEM Office of Water Resources, U.S. Environmental Protection Agency (USEPA), Pawcatuck Watershed Partnership WUSG, RIDEM Division of Fish and Wildlife (RIDFW), USEPA New England Regional Lab, Rhode Island Watershed Watch, and other public agencies, private organizations, and individuals who provided assistance, guidance and information during the study. Particular thanks are given to volunteers, including members of the Audubon Society of Rhode Island, Wood-Pawcatuck Watershed Association (WPWA), RI Trout Unlimited (TU), The Nature Conservancy (TNC), RIDEM, USEPA, and other individuals who provided field assistance with habitat assessments during this study. The cooperation of public and private landowners, who granted permission to access and sample the Usquepaug–Queen River and its tributaries, is appreciated.

STUDY METHODS

This report provides (1) descriptions of stream habitat and habitat availability at different streamflows; (2) data showing stream temperatures collected at eight sites during summer 2000; (3) data collected between 1998 and 2000 showing fish community composition for mainstem and tributaries sites; (4) flow-management targets determined by means of the RVA and statistical summaries of the streamflow regimes of the Usquepaug–Queen River in comparison with streamflow regimes in nearby rivers in Rhode Island, Connecticut, and Massachusetts; and (5) determinations of streamflow requirements for habitat protection by use of the Tennant, Aquatic-Base-Flow (ABF), Wetted-Perimeter, and R2Cross methods. These descriptions and statistical summaries can be used by water managers to guide the determination of appropriate streamflows for the protection of stream habitat.

Habitat Assessment

A reconnaissance of the mainstem and selected tributaries of the Usquepaug–Queen River Basin was conducted to identify stream macrohabitats and to determine accessibility of potential sampling sites. The river can be subdivided into macrohabitats created by the combination of discrete channel geomorphic units with different types of valley geomorphology and riparian vegetation. Channel geomorphic units are homogeneous areas of a channel that differ in slope, water velocity, turbulence, flow-control structures, depth, and substrate characteristics from adjacent habitats. In general, riffles have steep gradients, fast flow velocities, shallow water depths, coarse-grained substrates (gravel, cobble, boulder), and turbulent surface flows that commonly contain small standing waves or white water. Runs have moderate gradients, moderate flow velocities and depths, a variety of substrates (sand and gravel), and somewhat turbulent

but unbroken surfaces. Glides have low gradients and velocities, variable depths, fine-grained substrates (fine gravel, sand, organic detritus), and smooth surfaces. Pools have low gradients, moderate to deep water depths, fine-grained substrates (sand, silt, organic detritus), and slow velocities that are barely detectable or do not show at the surface. Impoundments are large pools behind artificial dams or beaver dams. Channel geomorphic units can be further subdivided into finer levels, such as log-enhanced or rootwad-, boulder-, or bedrock-formed lateral scour pools (Bain and Stevenson, 1999), but this level of classification is not used in this report.

For this study the Usquepaug–Queen mainstem was defined to include the Usquepaug River from Route 2 to Glen Rock Reservoir and the Queen River from Glen Rock Reservoir to the mouth of Fisherville Brook. The portion of the Queen River upstream of the mouth of Fisherville Brook was considered to be a tributary to the mainstem Queen River. Habitat-assessment study sites were selected to represent the different habitats available in the mainstem and tributaries, and to determine streamflow requirements for habitat protection. The most intensive data-collection efforts were focused on riffle reaches. Riffle reaches were targeted as critical areas for investigation of streamflow-habitat relations and for determination of streamflow requirements for habitat protection because of their sensitivity to low flows. During declining flows, riffles are among the first reaches to show habitat losses or to develop fish-passage problems.

Multiple visits were made to study sites by volunteer and USGS teams to document habitat availability and quality at different flows. Most visits, however, were made in summer during periods of low flow. USEPA rapid-bioassessment protocols (RBP) (Barbour and others, 1999) were used to evaluate and document stream-habitat quality within each study reach. Volunteers were trained in 1999 and 2000 in the use of the RBP. Volunteers were provided with RBP manuals, data sheets, and digital cameras, along with habitat assessment, wading, and safety equipment. The WPWA and Rhode Island Watershed Watch assisted with the coordination of volunteer sampling activities and the storage of data and photos collected by the volunteers. Multiple habitat assessments were conducted at two study sites for the purposes of quality assurance.

The RBP scores stream-habitat quality by use of 10 metrics that rate general categories of stream habitat for low-gradient streams: available cover, channel substrate, pool variability, sediment deposition, channel-flow status, channel alteration, channel sinuosity, bank stability, bank-vegetation protection, and riparian-zone width (Barbour and others, 1999). The RBP uses different metrics for high and low gradient reaches of streams. For high-gradient reaches, velocity/depth regime, embeddedness, and frequency of riffles are substituted for pool variability, channel substrate, and channel sinuosity, respectively (Barbour and others, 1999). Because of the moderate gradient of the Usquepaug–Queen and the predominance of coarse-sand and fine-gravel substrate, habitat assessments were completed for sites by use of RBP habitat-assessment field-data sheets that combined metrics for low-gradient and high-gradient streams. Each RBP metric is scored numerically between 0 and 20; scores from 0 to 5 are considered poor habitat, scores from 6 to 10 indicate marginal habitat, scores from 11 to 15 indicate suboptimal habitat, and scores from 16 to 20 indicate optimal habitat. If each metric is rated with an optimum score of 20, the total score would be 200. Scores of 160 to 200 are considered optimal, 110 to 159 suboptimal, 60 to 109 marginal, and < 60 poor. The scores for three of the ten metrics (available cover, velocity/depth regime, and channel-flow status) are dependent on the flow at the time the survey is made; therefore 30 percent of the total score is related to streamflow. Because a portion of the total score reflects features independent of flow, such as width of the riparian zone, the minimum scores are never zero, even if the river has no flow or is dry.

Stream-Temperature Assessment

Most methods for determining minimum streamflows for habitat protection are based on the assumption that summer low flow and habitat availability are limiting criteria for aquatic life. Other criteria affected by low flows, however, such as stream temperature and percent saturation of dissolved oxygen, can also be limiting factors that define suitable habitat. Water temperature is very important for the health and survival of native fish. Temperature regimes can influence migration, egg maturation, spawning,

incubation success, growth, the ability to compete for food and avoid predators, and resistance to parasites, diseases and pollutants (Armour, 1991).

To assess the suitability of summer stream temperatures for cold-water fish species, stream-temperature data were collected at eight sites on the Usquepaug–Queen River during the summer of 2000. Temperature data were collected at half-hour intervals with Onset Computer StowAway TidbiT dataloggers. To protect the dataloggers and to reduce the effects of direct sunlight and ground-water discharge on recorded temperatures, dataloggers were installed at the bases of staff gages inside short lengths of perforated PVC pipe and slightly above the streambed. A quality-assurance test of the dataloggers was completed upon removal of the dataloggers from the river. The test, made with a National Institute of Standards and Technology certified thermometer, showed the temperatures to be accurate, and variability between dataloggers to be less than 1°F.

For this report, the suitability of stream temperatures in the Usquepaug–Queen River for cold-water fish were indicated only through comparison of summer daily stream temperatures to critical and optimum ranges for brook trout (Elliot, 1994), and by comparison of 7-day moving averages to temperature criteria for maximum weekly average temperatures (MWAT), and short-term maxima (STM) for juvenile and adult brook trout (Armour, 1991). Temperature criteria for water-quality standards are generally applied for time-averaged characteristics of temperature such as the warmest 7-day average of daily maximum and mean temperature. Trout also respond to other temperature variables, however, such as maximum daily temperatures, mean daily temperatures, mean monthly temperatures, minimum diel fluctuations (difference between daily maximum and minimum temperatures), and cumulative thermal history (Sullivan and others, 2000). Because water-temperature tolerance varies between species and life stages, a complete assessment of the suitability of stream temperatures in the Usquepaug–Queen River for cold-water fish would include the stream-temperature requirements for different life-history stages (embryo/alevin, juvenile, adult) and activities (incubation, rearing, migration, spawning) for different cold-water species, and would also consider other important temperature-related factors, such as diurnal temperature fluctuations and the connectivity of cold-water refugia.

Fish-Community Assessment

Fish-community data were acquired from recent fish sampling conducted by the RIDFW during 1998, and by the New England Regional Laboratory of the USEPA during 2000. The 1998 RIDFW data include 12 samples from tributary and Queen River headwater streams, and 3 samples from the Usquepaug–Queen River mainstem. The 2000 USEPA data include only three samples, one each from the Queen River headwaters, the mainstem Queen River, and the mainstem Usquepaug River. Fish were sampled by electrofishing with direct current (DC) backpack units. Backpack shockers are best used in small or shallow streams. Backpack electrofishing was appropriate for sampling most reaches of the Usquepaug–Queen River and its tributaries during summer low flows. Backpack electroshockers could not be used for deeper habitats such as impoundments, flow-through ponds, and some of the deeper pools, and these reaches were not sampled.

Fish were classified into three macrohabitat classes on the basis of their habitat use: macrohabitat generalists (MG), fluvial dependents (FD), and fluvial specialists (FS) (Bain and Knight, 1996; Bain and Mexler, 2000). Macrohabitat generalists, such as pumpkinseed and redfin pickerel, are fish species or size classes that use a broad range of habitat; they include species commonly found in lakes, reservoirs, and streams, and can complete their life cycle in any of these systems. Fluvial dependents, such as white suckers, require access to streams or flowing-water habitats for a specific life stage, but otherwise commonly are found in lakes and reservoirs or ponded habitats. Fluvial specialists, such as brook trout and fallfish, almost always are reported as present in streams or rivers and require flowing-water habitats throughout their life cycle (Bain and Travnichek, 1996).

A modification of habitat classifications was developed by M.B. Bain (U.S. Geological Survey, written commun., 2000) to accommodate regional differences in habitat requirements. Habitat classifications for four species (fallfish, creekchub suckers, long-nose dace, brook trout) were changed from macrohabitat generalists to fluvial dependents or fluvial specialists. American eel, a catadromous fish that requires access to stream habitats for a portion of its life cycle, was classified as a macrohabitat generalist for the purposes of this report because it occupies a

wide range of habitats during the portion of its life cycle in freshwater streams. Stocked fish, including Atlantic salmon and brown trout, were not included in the fish-community analysis. Young-of-the-year were included in the analysis because length-distribution data that could be used to separate out young-of-the-year were not available.

Determination of Streamflow Requirements for Habitat Protection

A diagnostic method and four standard-setting methods (Instream Flow Council, 2002) were used for determination of streamflow requirements for habitat protection. The diagnostic method is the Range of Variability Approach (RVA) (Richter and others, 1997). The standard-setting methods include two office methods, the Tennant method (Tennant, 1976), and the New England Aquatic-Base-Flow (ABF) method (U.S. Fish and Wildlife Service, 1981; Lang, 1999); and two field-based methods, the Wetted-Perimeter method (Nelsen, 1984; Leathe and Nelson, 1986; Lohr, 1993), and the R2Cross method (Espegren, 1996, 1998; Nehring, 1979).

Methods Based on Streamflow Records

The RVA, Tennant, and New England Aquatic-Base-Flow methods use statistical measures of discharge-time series values to determine streamflow requirements, and require long-term records from a gaging station. In general, these methods should be applied to gaged sites only if unregulated flow data are available, and can be applied to ungaged sites only by regionalizing flow statistics at gaged sites or by simulating natural flows (that is, simulating streamflows without water withdrawals). Streamflow data from the Usquepaug River near Usquepaug stream gaging station (01117420) were used in the RVA, Tennant and ABF methods in this report. The streamflows at this gaging station are affected by upstream water withdrawals, but they are used in this report to provide an initial estimate that would provide a lower limit for the flow requirements determined by those methods. The USGS is currently developing a precipitation-runoff model based on the Hydrologic Simulation Program—FORTRAN (HSPF) program for analysis of the effects of water withdrawals on streamflow. Once the model is completed, streamflows without withdrawals can be simulated for the Usquepaug gaging station and for other locations in the basin; target streamflows determined by the RVA and streamflow requirements determined by the Tennant and ABF methods can then be recalculated. It is likely that the streamflow requirements calculated on the basis of simulated flows without withdrawals will be slightly higher than those determined from the historical record.

Indicators of Hydrologic Alteration and Range of Variability Approach

Current strategies for managing, maintaining, or restoring riverine fishery and aquatic wildlife resources and processes (Poff and others, 1998; Instream Flow Council, 2002) suggest that the native biodiversity and integrity of river ecosystems can be sustained by maintenance of the natural pattern of flow variability that created that diversity. The Indicators of Hydrologic Alteration (IHA) and RVA methods (Richter and others, 1996; 1997) were developed by the Nature Conservancy to assess the range of variation of discharge for a river and to define flow targets for river ecosystem management.

The IHA method characterizes the range of variation of discharge at a site by using a suite of 33 hydrologic statistics. Half of these statistics measure the central tendancy of the magnitude or rate of change of flow, and half focus on the magnitude, duration, timing, and frequency of extreme events. The statistics are divided into five general groups (table 1). Flow statistics such as monthly means are measures of the magnitude of flow and are general measures of the availability of habitat attributes such as wetted area, depth, or habitat volume. Flow statistics for the minimum and maximum average discharge for a given number of consecutive days (n-day flow statistics) are measures of the magnitude and duration of particular flow and provide measures of environmental stress and disturbance. The timing of lowest and highest flows throughout the year can provide a measure of seasonal disturbance or stress. The frequency and duration of time over which a specific flow exists may determine whether a particular life-cycle phase can be completed or the degree to which stressful effects such as dessication can accumulate. The rate and frequency of change in flow may be related to the stranding of certain organisms along the water's edge or in pools (Richter and others, 1996).

Table 1. Range of Variability Approach: flow statistics for characterization of hydrologic variation

[Source: Richter and others, 1996]

Hydrologic attribute	Statistical parameter
The magnitude of monthly discharge	Mean monthly discharge for each month.
The magnitude and duration of annual extreme discharge	Annual minimum and maximum for 1-, 3-, 7-, 30-, and 90-day periods; number of zero-flow days; 7-day minimum flow divided by mean flow for year.
The timing of annual extreme discharge	Julian date of the annual minimum and maximum daily flow.
The frequency and duration of high and low flow	Number of low-flow and high-flow pulses per year; mean duration of low-flow and high-flow pulses.
The rate and frequency of hydrographic change	Means of all positive and negative flow differences between consecutive daily means; number of flow rises and falls.

In this report, the IHA is used to describe the range of variation of streamflows at the gaging station on the Usquepaug–Queen River at Usquepaug (01117420). The flow regime in the Usquepaug–Queen is mostly unaffected by water withdrawals during fall, winter, and spring (October to May). Streamflows in summer (June to September), however, are reduced because of water withdrawals upstream of the Usquepaug gaging station. Because of these withdrawals, and to compare flows in the Usquepaug–Queen River to flows of nearby rivers, the IHA flow statistics for the Usquepaug River near Usquepaug gaging station (01117420) are compared to those determined from streamflow data from nearby rivers in Rhode Island, Connecticut, and Massachusetts.

Richter and others (1997) developed an adaptive-management approach, known as the RVA. The RVA defines flow targets for river-ecosystem management for each of 33 flow statistics determined by means of the IHA. Richter and others (1997) defined these flow targets as either 1 standard deviation from the mean flow or the range between the 25th and 75th percentiles (the interquartile range, or IQR) of the mean flow. Because hydrologic data often depart from a normal distribution, the IQR was used as the measure of flow variability for this report. Different ranges could be used to define flow targets; for example, a recent release of the IHA software uses the 33rd and 66th percentiles to define a more narrow flow-target range for the RVA (Smyth Scientific Software, v. 5.0.0 Beta Build 3, written commun., 2002).

Tennant Method

The Tennant method bases its streamflow requirements on the observation that aquatic habitat conditions are similar in streams carrying the same proportion of the mean annual flow (Q_{MA}). The method establishes streamflow requirements by means of a predetermined percentage of the mean annual flow (Tennant, 1976), and associates aquatic habitat conditions with different percentages of mean annual flow (table 2). The Tennant method is less sensitive to summer water withdrawals than methods that use low-flow statistics to determine streamflow requirements, because the Tennant streamflow requirements are derived from the mean annual-flow statistic which is largely determined by high flows.

The Tennant method has different criteria for winter (October–March) and summer (April–September) flow periods. Minimum streamflows for small streams during summer are established by the Tennant method by use of the 40-, 30-, and 10-percent Q_{MA} (Annear and Conder, 1984), which represent good, fair, and poor habitat conditions, respectively, according to Tennant. At 30 percent of the Q_{MA}, most of the stream substrate is submerged, but at 10 percent of the Q_{MA}, half or more of the stream substrate can be exposed (Tennant, 1976). The 30-percent Q_{MA} value is often used to determine minimum streamflow requirements in summer. A modification of the Tennant method, used in the Canadian Atlantic Provinces, designates 25 percent of the Q_{MA} as the minimum streamflow requirement in summer (Dunbar and others, 1998).

New England Aquatic-Base-Flow Method

The ABF method sets default streamflow requirements for use in regulated rivers, rivers that have a drainage area of less than 50 mi^2, ungaged rivers, or rivers that have streamflow gaging stations that have a period of record of less than 25 years or that have poor-quality records. The ABF-method default streamflow requirements are 0.5 $ft^3/s/mi^2$ for summer, 1.0 $ft^3/s/mi^2$

Table 2. Relations between aquatic-habitat condition and mean annual flow described by the Tennant method for small streams

[Source: Tennant, 1976. Q_{MA}, mean annual flow; <, less than]

Aquatic-habitat condition for small streams	Percentage of Q_{MA}, April–September	Percentage of Q_{MA}, October–March
Flushing flows	200	200
Optimum range	60–100	60–100
Outstanding	60	40
Excellent	50	30
Good	40	20
Fair	30	10
Poor	10	10
Severe degradation	<10	<10

Table 3. Seasonal New England Aquatic-Base-Flow default streamflow requirements

[Source: U.S. Fish and Wildlife Service, 1981. $ft^3/s/mi^2$, cubic foot per second per square mile]

Season (months)	Period	Instantaneous streamflow ($ft^3/s/mi^2$)
Summer (mid-June to mid-October)	low flow	0.5
Fall/Winter (mid-October to March)	spawning and incubation	1.0
Spring (April to mid-June)	spawning and incubation	4.0

for fall and winter, and 4.0 $ft^3/s/mi^2$ for spring (table 3). For free-flowing, unregulated rivers that have a drainage area of greater than 50 mi^2, and that have streamflow gaging stations with good-to-excellent quality records and a period of record of greater than 25 years, the ABF uses data from streamflow gaging stations to determine streamflow requirements. For these rivers, summer streamflow requirements are determined from the median of monthly mean flow for August (August median flow), fall and winter streamflow requirements are determined from the February median flow, and spring streamflow requirements are determined from the April and May median flows. August is assumed to represent the month of greatest stress for aquatic organisms because of the combination of low flows and high temperatures. The U.S. Fish and Wildlife Service (USFWS) calculates the ABF August-median flow statistic as the median of the monthly mean flows for August over the period of record (U.S. Fish and Wildlife Service, 1981; Lang, 1999). To make this calculation, a monthly mean flow statistic is first determined for each year by averaging the 31 daily mean flows in the month of August; then these monthly mean values (one for each year of the period of record) are combined and ranked, and the median value is taken. An August-median flow statistic can also be calculated as the median of the daily mean flows for all August days over the period of record (Charles Ritz Associates, 1987; Ries, 1997). To make this calculation, the 31 daily mean flows for August for each year are combined with the daily mean flows from all other August days (31 for each year of the period of record) and ranked, and the median value is taken. Consequently, "August median flow" statistics calculated as the median of the monthly mean flows for August and the median of the August daily mean flows are not equivalent. The USFWS method of calculating an August median flow statistic was designed to identify resource-conservative flows. Medians calculated from monthly mean streamflows tend to be higher than those calculated from daily mean streamflows because a small number of storms skew the monthly mean values upward, and the effects of land and water use tend to skew the daily mean values downward (Lang, 1999).

Methods Based on Physical and Hydraulic Characteristics

The R2Cross and Wetted-Perimeter methods require site-specific physical and hydrological data at a riffle cross section. Field-data collection for the Wetted-Perimeter and R2Cross analyses included surveys of stream-channel cross sections and water-surface slopes, and field determinations of bankfull elevations. Several cross sections were surveyed within the riffles. The distance between the cross sections was about one channel width. Staff gages were installed on trees or bridge abutments to provide vertical control for surveying cross-section profiles and water-surface elevations. Landscape nails about 1 ft in length were installed in the streambed at multiple cross sections. Surveys of staff gages, bed-nails, cross sections and water levels were made with a laser theodolite. Levels were run independently at each site and were not surveyed to sea level. Sites were revisited to measure discharge and water-surface elevations over the nails.

Application of the Wetted-Perimeter and R2Cross methods requires development of a stage-discharge relation for a riffle and determination of hydraulic parameters (mean depth, mean velocity, and wetted perimeter) for a range of flows. Stage, discharge, Manning's *n*, and water-surface slopes were used in Manning's equation to develop stage-discharge relations for the surveyed riffle cross sections. Manning's equation is:

$$Q = (1.486/n)A\ R^{0.67}S^{0.50},$$

where

- Q is discharge, in ft^3/s,
- 1.486 is the conversion factor for use with English units,
- n is the Manning's roughness coefficient,
- A is the cross-sectional area of the channel, in ft^2,
- R is the hydraulic radius, in ft, and
- S is the energy gradient, which was approximated by the friction slope, (S_f), in ft/ft.

Stage-discharge relations and hydraulic parameters were determined for this report primarily by application of Manning's equation to a single cross section by means of WinXSPRO (U.S. Department of Agriculture, 1998). Measurement of discharge and water-surface slope at low flow were used in Manning's equation to determine an initial value for channel roughness (*n*). The water-surface slope was then used as a boundary condition and Manning's *n* was varied to calibrate the model to the water levels for the measured discharges. Channel roughness was varied linearly between the calibrated value and a roughness value at bankfull flow that was estimated by comparison of the stream channel to photographs in Barnes (1967) and Hicks and Mason (1991). Stream slope was varied for low and high flows between values measured at the riffle cross section, and a more general water-surface slope measured over a longer reach of the stream. For each cross section, staging tables were developed showing stage, mean depth, mean velocity, and wetted perimeter for each discharge. The staging tables were used to construct graphs for determination of streamflow requirements by use of the Wetted-Perimeter method, and to determine streamflow requirements for habitat protection on the basis of the R2Cross hydraulic criteria.

One requirement for application of Manning's equation is a condition of uniform flow. Conditions that tend to disrupt uniform flow include bends in the stream course, changes in cross-section geometry, obstructions to flow caused by large roughness elements (sand bars, boulders, woody debris), or other channel features that cause convergence, divergence, acceleration, or deceleration of flow (U.S. Department of Agriculture, 1998). These non-uniform flow conditions can be evaluated if flows are gradually varying by use of one-dimensional, steady state, step-backwater, water-surface-profile models such as HEC-2, HEC-RAS, or WSPRO. These flow models use multiple cross sections, and can be used to identify backwater effects not accounted for by single-section applications of Manning's equation. To compare differences between different flow models, hydraulic parameters were determined for two sites by use of Manning's equation, with WinXSPro (U.S. Department of Agriculture, 1998) and by use of the U.S. Army Corps of Engineers' River Analysis System (HEC-RAS; Brunner, 2001).

Wetted-Perimeter Method

The Wetted-Perimeter method is based on the assumption that there is a direct relation between the wetted perimeter in a riffle and fish habitat in streams (Annear and Conder, 1984; Lohr, 1993). The wetted perimeter of a stream, the width of the streambed and stream banks in contact with water for an individual cross section, is used as a measure of the availability of aquatic habitat over a range of discharges (Annear and Conder, 1984; Nelsen, 1984). Use of the Wetted-Perimeter method to determine streamflow requirements requires a plot of the relation between wetted perimeter and discharge (fig. 3). The streamflow required for habitat protection is usually chosen as the point of maximum curvature in this relation. On a stream cross section, this point theoretically corresponds to the break in slope at the bottom of a stream bank (toe-of-bank) where the water surface recedes from the stream banks as flows decrease, or rises up the banks as flows increase.

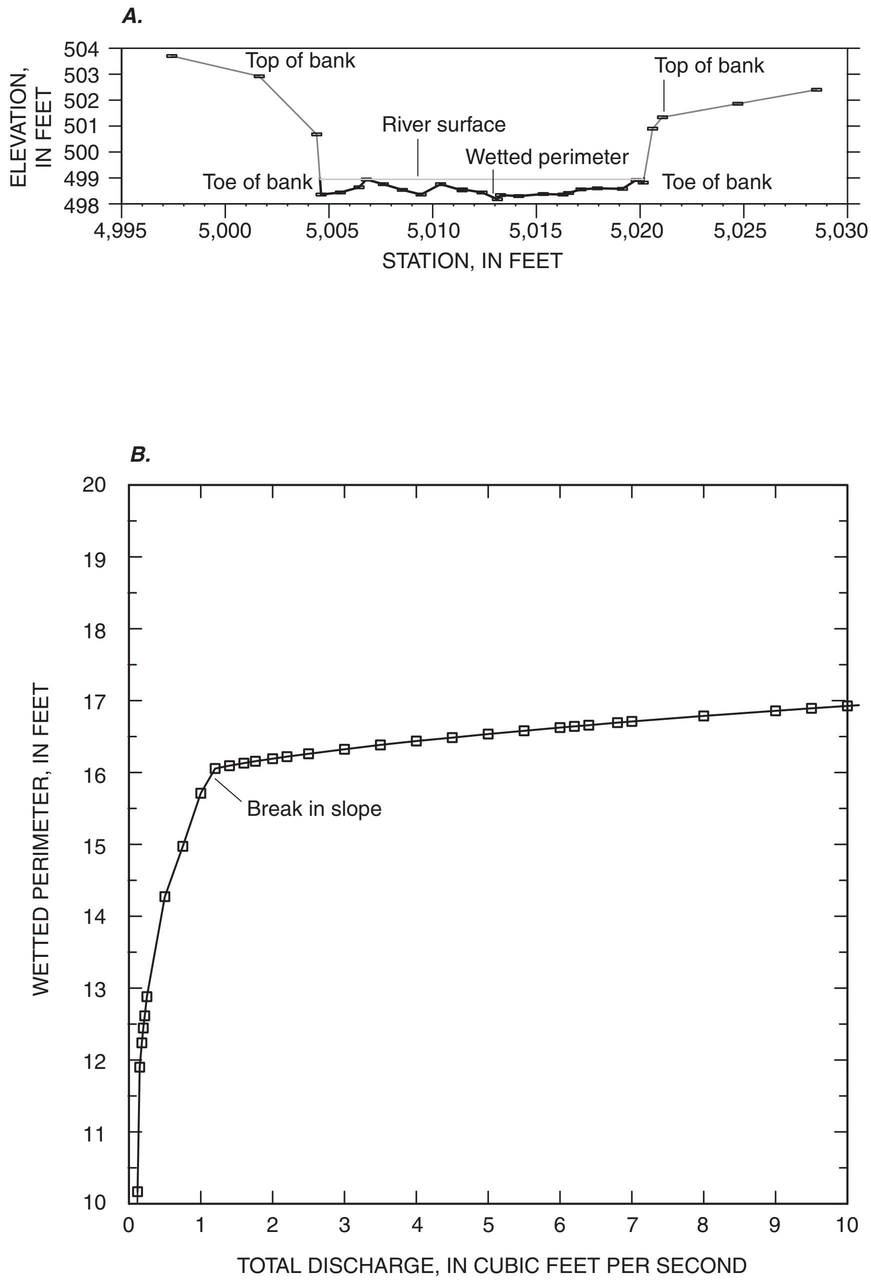

Figure 3. Diagram showing example of (*A*) a stream-channel cross section and graph showing (*B*) the relation between wetted perimeter and discharge.

Stream-channel geometry varies considerably, and the effectiveness of the Wetted-Perimeter method can be highly dependent upon the cross sections selected in the field. The break in slope in plots of wetted perimeter versus discharge is most distinct for channels that have sharp breaks in slope between the streambed and streambanks; water levels that rise above the bottom of the bank cause smaller rates of increase in wetted perimeter, and water levels that fall below the bottom of the bank cause larger rates of decrease in wetted perimeter. In practice, many conditions contribute to multiple breaks in slope or the lack of a distinct break point in the wetted-perimeter-to-discharge relation. Multiple break points can correspond to water rising over distinct features of the channel such as bars, boulders, or an irregular channel bed or banks. Less well-defined break points may also be a function of the number, density, and location of points surveyed along a cross section.

For this study, the most detailed cross sections were surveyed at the upstream ends of riffles that served as hydraulic controls. Hydraulic controls are sections or reaches of the channel, such as riffles, which eliminate the effects of downstream conditions on the velocity and depth of flow upstream of the section. Care was taken to survey points along the cross section where the slope of the streambeds or banks changed. When well-defined, the break in slope at the bottom of a stream bank was surveyed to identify the elevation that corresponds to a fully-wetted channel bed. These elevations were used to aid in establishment of streamflow requirements during analysis of those cases where break points were multiple or could not be clearly discerned.

R2Cross Method

The R2Cross method requires selection of a critical area of the stream, such as a riffle, and assumes that a discharge chosen to maintain habitat in the riffle is sufficient to maintain fish habitat in nearby pools and runs for most life stages of fish and aquatic invertebrates (Nehring, 1979). The streamflow required for habitat protection in a riffle is determined from the flow that meets criteria for three hydraulic parameters: mean depth, percent of bankfull[1] wetted perimeter, and average velocity (table 4). The depth criterion requires a mean depth that is at least 1/100 of the stream-top width, and has a lower limit of 0.2 ft. The wetted-perimeter criterion requires a wetted perimeter that is at least 50 percent of the bankfull wetted perimeter for streams less than 50 ft in width, a percentage equal to the top width (to the nearest ft) for streams between 50 and 60 ft in width, or 70 percent of the bankfull wetted perimeter for streams greater than 60 ft in width. The velocity criterion requires an average velocity of at least one foot per second (G. Espegren, Colorado Water Conservation Board, written commun., 2001).

The hydraulic criteria used in R2Cross were developed in Colorado to quantify the amount of streamflow required to "preserve the natural environment to a reasonable degree" (Espegren, 1996). The R2Cross method has been found to produce biologic flow recommendations that are very similar to those determined by more data-intensive techniques such as the Instream Flow Incremental Methodology (Nehring, 1979; Colorado Water Conservation Board, 2001).

To account for seasonal streamflow variability, the R2Cross method establishes different streamflow requirements for the summer and winter seasons. Streamflow recommendations in Colorado are based upon the streamflow that meets three hydraulic criteria in summer, and two of three hydraulic criteria in winter. In Colorado, however, flows are generally higher in spring and summer (April–August), because of snowmelt runoff, and lower in late summer, fall, and winter (September–March). In Rhode Island, flows are

Table 4. R2Cross criteria for hydraulic parameters for protection of aquatic habitat

[Source: Espegren, 1996. ft, foot; ft/s, foot per second; ≥, actual value is greater than or equal to the value shown]

Stream-top width (ft)	Mean depth (ft)	Percentage of bankfull wetted perimeter (percent)	Mean velocity (ft/s)
1–20	0.2	50	1.0
21–40	0.2–0.4	50	1.0
41–60	0.4–0.6	50–60	1.0
61–100	0.6–1.0	≥ 70	1.0

[1]The term "bankfull discharge" is used in this report to refer to the ordinary high-water line defined by MacBroom (1998) as the level along the bank that separates the predominantly aquatic and terrestrial areas. This level is evident from scour marks, soils, stain lines, and changes in vegetation due to the prolonged presence of water.

generally lowest in midsummer and early fall (July–September). For this study, R2Cross streamflow recommendations were established at flows that meet all three hydraulic criteria. Use of three hydraulic criteria will result in more conservative streamflow requirements from this method than use of two of three criteria (Annear and Conder, 1984). However, unlike mountain-runoff streams in Colorado, streams in Rhode Island have additional stresses during summer months that are linked to low streamflows, such as high stream temperatures and low dissolved-oxygen concentrations. The habitat quality corresponding to the streamflows that meet two of three R2Cross hydraulic criteria or that meet lower hydraulic criteria would need additional evaluation before being adopted for use in Rhode Island.

CHARACTERIZATION OF STREAM HABITAT, TEMPERATURE, AND FISH COMMUNITIES

The Usquepaug–Queen River can be broadly described as a small-order, low-gradient river. The mainstem portion of the river, between Route 2 and the confluence with Fisherville Brook, is a low-gradient stream that flows over a sand and gravel streambed through forested areas and shrub wetlands. The headwaters and tributaries of the river generally have a higher gradient and coarser bed materials than the mainstem, and flow through forested areas.

The topographic relief of the mainstem Usquepaug–Queen River leads to a predominance of low-gradient glide-and-pool habitat that has slow water velocities and smooth, unbroken water surfaces. The type of cover in this habitat is closely related to the type of riparian vegetation along the channel and the degree of canopy closure. In forested reaches where riparian vegetation is mostly trees and shrubs, the stream is typically shaded, and cover is created by woody debris in the channel, and by overhanging shrubs, undercut banks, and exposed roots along the stream margins. In wetland reaches where riparian vegetation is mostly shrubs, grass, sedge, and herbaceous vegetation, or wider reaches where the stream canopy is mostly open to sunlight, cover is created by submerged aquatic vegetation in the channel and by overhanging shrubs and emergent aquatic vegetation along the stream margins.

The Usquepaug River between Routes 2 and 138 is mostly forested glide-and-pool habitat. Downed trees and woody debris are common and can create narrow runs where trees partially block the channel or deep scour pools if the current is directed down into the streambed. The reach contains several small riffles that have formed where the river flows over material that has been eroded from a deep scour hole, where a narrowing of the valley has constricted the channel, or where the river has meandered near the sides of the valley and eroded into coarser substrate. Because the overall stream gradient is relatively low, and the drop in elevation over these riffles tends to be small, most riffles are present only during low-flow periods, and become fast, shallow runs when the riffles are submerged beneath moderate or high flows.

The largest riffle reach on the mainstem Usquepaug River is between Route 138 and the Glen Rock Reservoir Dam in South Kingstown. Like many of the larger riffles in New England streams, this reach appears to have alterations to the channel that probably were caused by activities associated with the operation of mills. Accordingly, the channel appears to be straightened, and the banks are hardened with riprap.

The Glen Rock Reservoir Dam is about 10 ft high, and creates an impoundment that extends upstream for more than a mile. The mainstem Queen River upstream of Glen Rock Reservoir flows mostly through low-gradient wetlands. Like the Usquepaug River, the Queen River is mostly glide-and-pool habitat, and the primary cover features are submerged aquatic vegetation and overhanging shrubs where the river is wide or where riparian vegetation is dominantly shrubs, grass, sedge, and herbaceous vegetation; and woody debris, undercut banks and exposed roots where the river passes through forested reaches. Two features found in the Queen River that are not common in the Usquepaug River are mid-channel sand bars covered with submerged or emergent aquatic vegetation, and islands and multiple channels created by channel avulsions. There are no large riffles in this segment, although there are several smaller riffles and runs that have gravel-and-cobble substrates.

The tributaries and headwater portions of the Queen River commonly have more riffle and run habitats than the mainstem. Fisherville and Locke Brooks have long reaches with moderate gradients that are predominantly riffle and pool habitats. Some reaches in the tributaries and headwaters contain glide-and-pool habitat. These reaches typically are near the

confluences of tributaries with the mainstem, where the tributaries extend into the lower-gradient Queen River Valley, or where they pass through isolated wetland reaches.

Habitat Assessments

Thirteen river reaches were selected to represent different habitats of the Usquepaug–Queen River and for investigation of streamflow-habitat relations. Seven of the sites were on the mainstems of the Usquepaug and Queen Rivers, and six were on the Fisherville and Locke Brook tributaries and in the Queen River headwaters (fig. 1). The river reaches were each about 11 channel widths in length. The 13 sites are composed of 7 sites that include riffle habitat, and 6 sites that are predominantly run habitat. Some of the run sites become riffles at very low flows. The riffle sites included four on the mainstem Usquepaug–Queen River (U2, U1, Q6, and Q5) and three on tributary or headwater streams (Q3, L1, F2). The run sites included three on the mainstem (U3, Q8, Q7,) and three on tributaries or headwater streams (Q4, Q2, F1). Six of the riffle sites were considered to be critical and were also used for determination of streamflow requirements for habitat protection (table 5).

Usquepaug River near Usquepaug (Site U3), South Kingstown

This reach is upstream of Route 2, between the USGS gaging station and a pull-off on the north side of Route 2. The drainage area to the study site is 36.1 mi^2 and the river channel averages about 30 to 40 ft wide. The study reach is within a meandering, low-gradient segment of the river that is predominantly glide-and-pool habitat with a sand streambed. The channel appears unaltered except near the bridge and where the river meanders close to the embankment along Route 2. The study reach is mostly glide, pool, and run habitats with a forest and shrub riparian area that partially shades the channel. A few patches of open canopy allow sunlight to penetrate to the streambed and facilitate growth of submerged aquatic vegetation. The river has numerous meanders, many of which have large pools on the outsides of bends. Some of these pools are 3 to 4 ft deep, even during periods of low flow. Cover in glide-and-pool habitat is mostly provided by downed trees, woody debris, overhanging shrubs, and submerged aquatic vegetation. The streambed through most of the reach is sand, except for one run, about one channel width in length, that has a streambed of gravel and cobbles embedded in sand.

As water levels decline, habitat losses first appear along the margins of sandbars located on the insides of meander bends; however, moderate water depths remain in the pools along the outsides of the meander bends. During very low flows, the run becomes a riffle, and water depths become quite shallow. During extreme low flows, the edge of water pulls away from the banks, and woody debris and vegetated sandbars provides minimal or no cover because of shallow water conditions (fig. 4).

Usquepaug River near Laurel Lane (Site U2), South Kingstown

This reach is downstream of Route 138, adjacent to the Laurel Lanes Golf Course and about 1,100 ft northwest of the end of Laurel Lane. The drainage area to the study site is 34.0 mi^2 and the river channel within the study reach averages about 30 to 40 ft wide. The study reach extends from an access road adjacent to the southern end of the Laurel Lanes Golf Course driving range to a small riffle adjacent to the northern end of the driving range. The study site is within a meandering low-gradient segment of the river that is predominantly glide-and-pool habitat with a sand streambed. The study reach includes one short riffle-and-run about one channel width in length. Stream velocity is mostly slow and depths vary throughout the reach. The channel and riparian zones are unaltered. The streambed is mostly coarse sand, except for the riffle, which has a boulder, cobble, and gravel streambed. The riparian vegetation is predominantly forest, and the channel is mostly shaded by trees, overhanging shrubs, and vines. Cover features in glides and pools are mostly provided by woody debris, undercut banks, overhanging shrubs, and deep water. Cover features in the riffle-and-run are provided by pockets of slower velocity water adjacent to boulders. An oxbow along the left bank is disconnected from the main channel during moderate and low flows. The oxbow is mostly filled with soft sediment and held shallow standing water during the early summer of 2000.

Table 5. Location and description of stations for habitat assessments, determination of streamflow requirements, temperature dataloggers, and fish sampling in the Usquepaug–Queen River Basin, Rhode Island

[**USGS Habitat Site ID**: First letter of stream name and downstream order along identified stream. Latitude is in degrees, minutes, seconds. X, activity at station. ID, identifier; USEPA, U.S. Environmental Protection Agency; USGS, U.S. Geological Survey; mi^2, square mile]

USGS Habitat site ID	Station name and location	Drainage area (mi^2)	Latitude ° ′ ″	Longitude ° ′ ″	Habitat assess-ment	Stream-flow require-ment	Temp-erture data-logger	USEPA fish sampling
U3	Usquepaug River near Usquepaug, upstream of USGS stream-gaging station (01117420), adjacent to pull-off along north side of Route 2	36.1	41 28 36	71 36 19	X		X	
U2	Usquepaug River near Laurel Lane, south of Usquepaug, adjacent to driving range	34.0			X	X		X
U1	Usquepaug River at Route 138, at Usquepaug, between Route 138 and Old Usquepaug Road	32.8	41 30 09	71 36 30	X	X	X	
Q8	Queen River, near Kingston Road, northeast of Usquepaug, adjacent to field on Eppley Audubon Sanctuary, 0.8 mile downstream of Liberty Road	21.2	41 31 49	71 34 44	X			
Q7	Queen River at Liberty Road at Liberty, downstream of USGS stream-gaging station (0117370)	19.1	41 32 20	71 34 09	X		X	
Q6	Queen River near Dawley Road northeast of Liberty, 0.5 mile downstream of Dawley Road	18.6	41 32 37	71 33 52	X			
Q5	Queen River near Dawley Road, northeast of Liberty, 650 feet downstream of Dawley Road	18.4	41 32 55	71 34 40	X	X	X	X
Q4	Queen River near School Land Road, southwest of Exeter, 0.4 mile downstream of William Reynolds Road, adjacent to former Ladd School pumphouse	4.22	41 33 25	71 32 59	X		X	X
Q3	Queen River at William Reynolds Road, southwest of Exeter, downstream of William Reynolds Road	3.75	41 33 45	71 32 54	X	X	X	
Q2	Queen River near William Reynolds Road, southwest of Exeter, 1,400 feet upstream of William Reynolds Road	3.69	41 33 57	71 32 51	X			
Q1	Queen River at Route 102 west of Exeter	2.80	41 34 43	71 32 37			X	
L1	Locke Brook at Mail Road, west of Liberty downstream of Mail Road	4.37	41 32 14	71 35 17	X	X	X	
F2	Fisherville Brook at Liberty Church Road, 400 feet downstream of Liberty Church Road	8.14	41 33 51	71 33 54	X	X	X	
F1	Fisherville Brook near Pardon Joslin Road northwest of Exeter, 0.3 mile downstream of Pardon Joslin Road, downstream of impoundment on the Rhode Island Audubon Society Fisherville Refuge	4.0	41 35 07	71 34 15	X	X		

Habitat quality was assessed by the USGS using the low-gradient RBP on September 13, 2000, at an estimated discharge of 25 ft^3/s (0.74 ft^3/s/mi^2). The habitat in the reach received a score of 179. Habitat scores were optimal in all categories except for channel sinuosity, which scored suboptimal.

Most of the habitat features in this reach are along the stream margins. On the outsides of meander bends, overhanging brush provides habitat during all but extreme low flows. A few deep pools on meander bends and beneath accumulations of woody debris may maintain depths of about 3 to 4 ft, even during low

A. Bend pool and exposed sandbar, upstream view

B. Submerged aquatic vegetation and overhanging vegetation, downstream view

Figure 4. Habitat features on the Usquepaug River, near Usquepaug (Site U3) South Kingstown, Rhode Island: (*A*) bend pool and exposed sandbar, upstream view, and (*B*) submerged aquatic vegetation and overhanging vegetation, downstream view.

A. Riffle and run habitat, upstream view

B. Woody debris, downstream view

Figure 5. Habitat features on the Usquepaug River near Laurel Lane (Site U2), South Kingstown, Rhode Island: (*A*) riffle-and-run habitat, upstream view, and (*B*) woody debris, downstream view.

flows. Once streamflows decline to enough for the edge of water to pull away from the stream banks, available habitat decreases greatly. In shallow reaches between bends, woody debris becomes exposed at low flows and may provide only minimal habitat despite spanning most of the channel. Streamflows that provide a fully-wetted channel across the riffle would provide sufficient depth for fish passage (fig. 5). At discharges near 15 ft^3/s the channel would be fully wetted, and all pools would contain water, but there would be almost no depth at the channel margins. At some locations, the streambed would be exposed along the margins, and overhanging shrubs would extend over shallow water or a dry streambed. Most undercut banks would be dry and many roots would be exposed.

Usquepaug River at Route 138 (Site U1), South Kingstown

This reach is about 400 ft upstream of State Route 138, and downstream of Old Usquepaug Road in South Kingstown. The drainage area to the site is 32.8 mi^2. The study reach is within a high-gradient segment that is mainly riffle-and-run habitat

A. Riffle habitat, downstream view

B. Riffle habitat, upstream view

Figure 6. Habitat features on the Usquepaug River at Route 138 (Site U1), South Kingstown, Rhode Island: (*A*) riffle habitat, downstream view, and (*B*) riffle habitat, upstream view.

downstream of Glen Rock Reservoir (fig. 6). The channel has a uniform cross section and is 25 to 35 ft wide. The river channel between Old Usquepaug Road and Route 138 is mostly straight, with a slight bend to the left. The channel may have been straightened, and the banks altered as part of a long history of mills and settlement at this location. However, none of the channel alterations appear to be recent. There is a stone wall along the right bank just downstream of Old Usquepaug Road and also upstream of the Route 138 bridge. The right bank has been reinforced with boulder riprap over most of its length, and the riprap is mostly covered with vines and shrubs. In the downstream portion of the reach, the riparian area on the right bank is maintained as lawn up to the edge of the bank. The left bank appears less altered. The upper portion of the study reach is predominantly riffle-and-run habitat, and the lower end of the reach upstream of the Route 138 bridge is run-and-pool habitat. Stream velocities are mostly fast throughout the reach. Depths are shallow (less than 1.5 ft at discharges up to about 40 ft^3/s) between the left bank and the center of the channel, and are deepest adjacent to the riprap along the right bank. The streambed is boulder, cobble, and gravel, along with broken rock, brick, and other debris. The streambed contains little sand and may be sediment-starved because of the impoundment upstream. Cover features in the riffle are provided by overhanging shrubs, a turbulent stream surface, and velocity shelters behind boulders, woody debris, and riprap. There are only minor amounts of woody debris and aquatic vegetation in the channel. The river is forested along the left bank, but a partially open canopy on the right bank and the north-south orientation of the river allow sunlight to reach the stream in the afternoon. Streamflow over the low-head dam upstream contributes warm water to the reach during the summer.

Habitat quality was assessed by volunteers and USGS teams using the high-gradient RBP on December 12, 1999, at a discharge of 53 ft^3/s (1.62 $ft^3/s/mi^2$), and again on September, 21, 2000, at a discharge of 34 ft^3/s (1.04 $ft^3/s/mi^2$) . The habitat in the reach received scores of 160 and 166, respectively. Habitat scores were mostly in the optimal range, with suboptimal scores related to channel alterations and the lack of deep-pool and slow-shallow habitat.

Pocket water (velocity shelters) behind cobbles and boulders in the steambed and behind riprap along the right bank provide the most habitat structure in this reach. At discharges near 15 to 20 ft^3/s the channel is fully wetted. There is flow over most cobbles in the riffle, and the tops of a few boulders are exposed. Overhanging shrubs extend over shallow water, and all pools contain water. At discharges near 10 ft^3/s the channel remains fully wetted, and velocities are lower. Slightly more of the boulder tops are exposed. Edgewater habitats along left bank are shallower than those along the riprap on the right bank. Because the channel is mostly rectangular or trapezoidal in cross section, shallow conditions develop throughout the reach as flows decline, and a decrease in water depth to the top of the cobbles exposes substrate throughout the

reach. Because of the flat streambed across the section, possibly created by channel alterations, low discharges of about 1 to 2 ft^3/s will wet the channel to the bottom of the bank identified in the field. However, water depths are extremely shallow at this low discharge value and are below the depth of the top of the cobbles and boulders in the streambed.

Queen River near Kingston Road (Site Q8), Exeter

This reach is about 0.8 mi downstream of Liberty Road and about 0.4 mi upstream of the confluence of the Queen River and Locke Brook. The drainage area to the study reach is 21.2 mi^2. The study site is about 400 ft long. The river is about 30 to 40 ft wide within the study reach. The channel and riparian zones are unaltered. The study site is within a meandering, low-gradient segment of the river that is primarily glide-and-pool habitat with a sand streambed. The riparian vegetation in the reach is mostly shrubs, with some habitat patchiness created by areas where there are trees on the stream bank or that have a higher percentage of trees or grass and other herbaceous vegetation. Stream velocity is slow and depths are mostly deep; the streambed is mostly soft sand. The remains of an old beaver dam and house were found in the upstream portion of the study reach. Silt and organic soil along the banks likely were deposited when there was a beaver pond at the site, and a small oxbow along the right bank may have been formed by flows bypassing the former beaver dam. Cover is provided by deep pools and a proliferation of submerged, floating, and emergent aquatic vegetation in shallower areas. Overhanging shrubs and vines and woody debris provide habitat along the stream banks (fig. 7).

Habitat quality was assessed by the USGS using the RBP on August 8, 2000, at a discharge of 28 ft^3/s (1.32 $ft^3/s/mi^2$), and the reach received a habitat score of 168. Habitat scores were optimal in all categories except for suboptimal scores associated with sediment deposition and a lack of pool variability.

Because of the low gradient, the stream channel tends to remain wetted bank-to-bank at low flows. Moderate to deep water depths remain in bend pools, even during low flows. As flows decline, water depths throughout the reach can become quite shallow over mid-channel sand bars that have beds of submerged aquatic vegetation, but narrow passages between the vegetated bars can provide threads of current and deeper-water habitat adjacent to the vegetation.

A. Vegetated sand bars, upstream view

B. Overhanging vegetation and deep pool, downstream view

Figure 7. Habitat features on the Queen River near Kingston Road (Site Q8), Exeter, Rhode Island: (*A*) vegetated sand bars, upstream view, and (*B*) overhanging vegetation and deep pool, downstream view.

Queen River at Liberty Road (Site Q7), Exeter

This study site is located downstream of the Liberty Road bridge over the Queen River in Exeter. The drainage area to the site is about 19.1 mi^2. The study reach begins downstream of the pool adjacent to the USGS stream-gaging station at Liberty Road,

(01117370), and extends for about 400 ft downstream. The study site is within a low-gradient reach of the river that is predominantly glide-and-pool habitat. The river is about 30 to 40 ft wide. The riparian vegetation is forested, and the channel is unaltered. Stream velocities through the reach are slow. The reach is mostly straight with mid-channel bars creating variable water depths. A few meanders provide deeper water in the bend pools. The streambed is mostly gravel and coarse sand. Cover features in the reach include undercut banks, overhanging shrubs, and woody debris. Submerged aquatic vegetation grows throughout the reach. Dense beds of submerged aquatic vegetation are on several large mid-channel bars (fig. 8).

Habitat quality was assessed by the USGS using the RBP on July 29, 1999, at a discharge of 2.4 ft^3/s (0.13 $ft^3/s/mi^2$). The habitat in the reach received a score of 159. Metrics for sediment deposition and channel sinuosity were scored suboptimal due to the presence of large mid-channel sand bars. The reach was assessed during a period of low flow. Consequently, metrics were scored suboptimal for available cover and marginal for channel-flow status.

Once flows decline enough for the edge of water to recede from the banks, most undercut banks, overhanging vegetation, and woody debris along channel margins can no longer provide habitat. A few deeper areas continue to provide some habitat at very low flows. At very low flows, water depths are shallow throughout the reach and may be only a few tenths of a foot deep over mid-channel bars that have dense beds of submerged aquatic vegetation.

A. Vegetated sand bars, upstream view

B. Shallow stream margins, downstream view

Figure 8. Habitat features on the Queen River at Liberty Road (Site Q7), Exeter, Rhode Island: (*A*) vegetated sand bars, upstream view, and (*B*) shallow stream margins, downstream view.

Queen River near Dawley Road (Site Q6), Exeter

The study site is about 0.5 mi upstream of Liberty Road and 0.5 mi downstream of the Dawley Road bridge over the Queen River, in Exeter. The study site is about 400 ft long. The drainage area to the site is 18.6 mi^2. The study site is within a moderate gradient reach of the river and contains a mix of riffle, run, pool, and glide habitats. The river is about 20 to 40 ft wide. The riparian area is predominantly forested and provides partial shade to most of the study reach. The stream channel appears unaltered, but there has been some clearing of woody debris and fallen trees along the banks for canoe passage. Stream velocities and depths are variable throughout the main channel. The streambed is mostly gravel, with sand in pooled areas. Cover in the channel is provided by deep water in bend pools, long undercut banks, overhanging shrubs, woody debris, and submerged aquatic vegetation (fig. 9). The stream has undercut the roots of many trees throughout the reach, some of which have dropped into the channel. The river has a multiple, anastamosing channel at some locations, possibly created during floods when debris jams diverted flow into the easily-eroded fine gravel and coarse sand streambanks. These side channels are 10 to 20 ft in width, hundreds of feet in length, and meander horizontally 50 ft or more from the main channel. The side channels provide a large area of shallow-water habitat.

A. Undercut trees, downstream view

B. Submerged aquatic vegetation, downstream view

Figure 9. Habitat features on the Queen River near Dawley Road (Site Q6), Exeter, Rhode Island: (*A*) undercut trees, downstream view, and (*B*) submerged aquatic vegetation, downstream view.

Habitat quality was assessed by volunteers and the USGS using the RBP on November 11, 1999, and the reach received a habitat score of 176. Habitat scores were all in the optimal range except bank stability, which was scored suboptimal because of the easily eroded banks.

The diversity of cover features in this reach provide habitat throughout a wide range of flows. As flows recede to the base of the stream banks, undercut bank habitat is lost, and the quality of habitat beneath overhanging vegetation declines. Once the water level drops enough for the edge of water to pull away from the banks, most stream-margin habitat is lost. Submerged aquatic vegetation and bend pools, however, continue to provide habitat in the main channel. There is a large loss of shallow-water habitat once flows drop enough for the side channels to become disconnected from the main channel. Some side channels may not dry completely during low flows and may contain shallow, isolated pools, possibly fed by ground-water discharge.

Queen River at Dawley Road (Site Q5), Exeter

The study site begins about 650 ft downstream of the Dawley Road bridge over the Queen River in Exeter, and extends for about 400 ft downstream. The drainage area to the site is 18.4 mi^2. The study site is within a low-to-moderate gradient reach of the river and contains a mix of habitat types. The river is about 30 to 40 ft wide. The reach is mostly forested, partially shading the channel; although a few sweeping meanders have a wider channel and an open canopy. The stream channel along the left bank is unaltered. Some woody debris and fallen trees have been cleared from the channel along the right bank. The study reach is predominantly glide-and-pool and slow-run habitat. Stream velocities and depths through the reach are variable. The reach contains one short riffle about two channel widths in length. The streambed is mostly coarse sand and fine gravel, with some cobble and boulders in the riffle. Cover in the channel is provided by moderate depths in bend pools, long undercut banks, overhanging shrubs, woody debris, and abundant submerged aquatic vegetation (fig. 10).

Habitat quality was assessed by volunteers and the USGS using the RBP on seven different dates in 1999 and 2000. The average score for the site was 170. Scores ranged from 184 on September 21, 2000, at a discharge of 18.5 ft^3/s (1.00 $ft^3/s/mi^2$) to 157 at a discharge of 8.8 ft^3/s (0.48 $ft^3/s/mi^2$) on July 10, 2000. Habitat scores were mostly in the optimal range except for channel sinuosity which scored suboptimal. Metrics for available cover, velocity-depth regime, and channel-flow status scored suboptimal during periods of low flow.

As flows decline, the quality of shallow-water habitat along stream margins decreases. When flows reach the base of the bank, undercut bank habitats supported by tree roots are among the first cover features lost. Once the edge of water pulls away from the banks, much of the habitat associated with overhanging vegetation and woody debris along the channel margins is lost. Beds of submerged aquatic

A. Riffle, upstream view

B. Left bank showing loss of stream-margin habitat at low flows, downstream view

Figure 10. Habitat features on the Queen River at Dawley Road (Site Q5), Exeter, Rhode Island: (*A*) riffle, upstream view, and (*B*) left bank showing loss of stream-margin habitat at low flows, downstream view.

vegetation and bend pools can continue to provide some mid-channel habitat during low flows. The quality of that habitat appears to decrease steadily, however, with further decreases in water velocity and depth. At discharges near 30–35 ft^3/s the channel is fully wetted. There is flow over most cobbles and boulders in the riffle. Overhanging shrubs in the glides and runs extend over shallow water at stream margins and undercut banks are partially filled with water. All pools contain water, and water depths and velocities through submerged aquatic vegetation are adequate to provide good habitat. At discharges near 10 ft^3/s the channel remains close to fully wetted. Some edgewater habitats are exposed and most of the undercut banks are dry. Cover provided by overhanging vegetation at the banks is greatly reduced. The tops of some boulders are exposed in the riffle. Water velocity and depth are noticably lower in the beds of throughly submerged aquatic vegetation. At a discharge of about 4 ft^3/s the channel is wetted to the left and right bottom-of-bank. Water depths at this discharge value are shallow and are near the top of the cobbles in the streambed.

Queen River near New School Land Road (Site Q4), Exeter

This reach is located about 0.4 mi downstream of the William Reynolds Road bridge over the Queen River, and about 0.3 mi upstream of the confluence of the Queen River and Fisherville Brook. The drainage area to the reach is about 4.17 mi^2. The study reach is 200 ft long, has a low to moderate gradient, and is located upstream of the abandoned sewage beds and adjacent to the pumphouse for the former Ladd School. Just downstream of the study site the stream enters Bear Swamp, where at some locations it divides into multiple channels and can be hard to follow. The river is about 10 to 20 ft wide, about half its width downstream of the confluence with Fisherville Brook. The riparian area is predominantly forested, and the stream channel is unaltered. The channel is mostly shaded by trees and shrubs. Stream velocities and depths through the reach are variable. The channel is sinuous, and has small pools in the meanders separated by shallow-run habitat between bends. The streambed is mostly coarse sand and fine gravel. Cover in the channel is provided by overhanging shrubs and sedges, woody debris, and moderate depths in bend pools (fig. 11).

Habitat quality was assessed by the USGS using the RBP on August 8, 2000, at a discharge of 4.71 ft^3/s (1.13 $ft^3/s/mi^2$). The habitat in the reach was scored at 158. The reach received suboptimal scores for sediment deposition and bank stability because of the easily eroded sand stream banks and the presence of sand bars.

Portions of this reach are very shallow during periods of low flow. Pools on meander bends may have 1–2 ft of water, but between pools where the channel commonly has a rectangular shape, water depths may be only a few tenths of a foot. As flows decline, pools can become almost isolated from one another by the

A. Shallow water, upstream view

B. Loss of habitat at stream margins, upstream view

Figure 11. Habitat features on the Queen River near School Land Road (Site Q4), Exeter, Rhode Island: (*A*) shallow water, upstream view, and (*B*) loss of habitat at stream margins, upstream view.

shallow intervening water depths. Most habitat features are along the stream margins, and little cover remains in the channel once the edge of water recedes from the stream banks.

Queen River at William Reynolds Road (Site Q3), Exeter

This reach is downstream of William Reynolds Road in Exeter. The study site is within a reach of the river with a low to moderate gradient. The drainage area to the site is about 3.75 mi^2. The study reach contains a mix of riffle, run, and pool habitats in approximately equal distribution. The river is about 20 ft wide. A forested riparian area creates a closed canopy that shades the channel throughout most of the reach. The study reach is mostly unaltered; however, the stream channel may have been straightened in the reach immediately downstream of the culverts beneath William Reynolds Road. The streambed is predominantly coarse sand and gravel except for a riffle about 50 ft downstream of William Reynolds Road, where the bed is cobble and gravel. Stream velocities and depths are variable along the reach. Midway through the study reach, two sharp meanders have created deep pools along the outside and sandbars on the inside of the meander bends. The stream banks are sand and gravel, and are undercut about a foot into the bank along most of the reach. Cover features in the reach are provided by undercut banks, bend pools, overhanging vegetation, and woody debris (fig. 12).

Habitat quality was assessed by volunteers using the RBP during training sessions on September 14, 1999, and June 14 and 24, 2000. The mean score assigned to the reach by the USGS and volunteer groups in September 1999 was 167. The habitat assessments were conducted during a period of low flow, and metrics for channel-flow status and velocity/depth regime were scored suboptimal. Streamflows were higher during the assessments made on June 14 and 24, 2000, and this was reflected in the mean scores which were 181 and 184, respectively. Metrics were scored suboptimal for velocity-depth regime because of the absence of deep pools. An assessment made by the USGS on July 12, 2000, at a discharge of about 0.93 ft^3/s (0.25 $ft^3/s/mi^2$) scored 172, and velocity/depth regime and channel-flow status were scored suboptimal. An additional assessment at a discharge of about 7.3 ft^3/s (1.9 $ft^3/s/mi^2$) on September 20, 2000, gave a score of 186.

As water levels decline, habitat losses are first visible in the riffle at the upper end of the study reach. Most of the riffle has a rectangular cross section and when flows drop to the bottom of the bank, water depths become very shallow, and the tops of cobbles are exposed. Once substrates are exposed, little depth remains in the riffle to provide habitat or fish passage between the cobbles. Any woody debris that lies on top of the rocky streambed also is exposed at low flow,

A. Riffle with rectangular cross section during low flow, downstream view

B. Loss of stream-margin habitat, upstream view

Figure 12. Habitat features on the Queen River at William Reynolds Road (Site Q3), Exeter, Rhode Island: (*A*) riffle with rectangular cross section during low flow, downstream view, and (*B*) loss of stream-margin habitat, upstream view.

and the undercut banks along the channel become too shallow to provide quality habitat, or are dry. In the lower end of the study reach, bend pools maintain moderate water depths as flows decline, but large habitat losses occur in the reaches between pools, where the sand and gravel that has been scoured out of the pools is deposited. On several occasions in 1999 small fish that were disturbed by wading were observed attempting to swim sideways through water about 1 in. deep to try to gain passage to upstream pools. At discharges near 6 ft^3/s, the tops of small boulders are exposed in the riffle, but the undercut banks are partly full and the channel is close to fully wetted. Some edgewater habitats are exposed, particularly in sandbars on the inside of meander bends.

Queen River near William Reynolds Road (Site Q2), Exeter

This reach is about 0.2 mi upstream of William Reynolds Road, and about 1 mi downstream of Route 102 in Exeter. The drainage area to the site is about 3.69 mi^2. The reach is located upstream of a small impoundment and downstream of the Exeter Country Club. The study site is within a reach of the river with a low to moderate gradient. Parts of the channel have been altered, although none of these alterations appear recent. There is a small constructed rock control at the lower end of the reach, and some portions of the channel have boulders that appear to have been placed along the banks to reduce erosion. The river is about 10 to 20 ft wide. The reach is predominantly glide-and-run habitat. The stream is narrow and the channel is shaded by riparian trees and shrubs. The streambed consists of a mix of gravel, cobbles, boulders, and coarse sand. Many downed trees and pieces of small woody debris are in the channel, and the stream banks have exposed roots and are undercut by about 0.5 ft throughout the reach. Depths and velocities in the stream are variable (fig. 13).

Habitat quality was assessed by volunteer groups using the RBP on October 15, 1999, at a discharge of about 2.4 ft^3/s (0.65 $ft^3/s/mi^2$), and again on July 14, 2000, at a discharge of about 1.4 ft^3/s (0.38 $ft^3/s/mi^2$). The habitat in the reach was scored at 168 in October and 161 in July. The reach is relatively straight and received suboptimal scores for sediment deposition, velocity-depth regime, channel-flow status, channel alteration, and frequency of riffles.

Overhanging shrubs and woody debris provide most of the habitat throughout the study reach. Once flows drop enough for the edge of water to pull away from the banks, the undercut banks along the channel become dry, and water depths beneath overhanging vegetation are very shallow. Because the channel is narrow, many of the trees that have fallen into the stream bridge the channel. These trees provide overhead cover, but are commonly out of the water and exposed even at moderate flows.

A. Woody debris, upstream view

B. Loss of stream-margin habitat

Figure 13. Habitat features on the Queen River near William Reynolds Road (Site Q2), Exeter, Rhode Island: (*A*) woody debris, upstream view, and (*B*) loss of stream-margin habitat.

Locke Brook at Mail Road (Site L1), Exeter

This reach is downstream of Mail Road in Exeter. The drainage area to the site is 4.37 mi^2. The study site has a moderate gradient and is predominantly riffle habitat. The study reach begins about 300 ft downstream of the Mail Road bridge, and extends about 600 ft downstream to a pool and large debris pile at a sharp bend in the river. The upper portion of the reach is lined with grass, sedge, and shrubs and has an open canopy, and the lower portion of the reach is lined with shrubs and trees and has a partly closed canopy. The channel and riparian area show evidence of alterations. The adjacent farm uses a wide, shallow riffle in the upstream portion of the reach as a ford for tractors to cross the brook, and the riparian area at the upstream end of the reach is mowed for hay within a few feet of the stream. The river is 20–30 ft wide. The reach is predominantly riffle-and-run habitat with a coarse sand, gravel, cobble, and boulder streambed. Cover in the upper portion of the reach is provided by submerged aquatic vegetation, and by velocity shelters behind cobbles and boulders. The stream is shallow; low banks and sedge hummocks line the channel in the upper portion of the reach. In the lower portion of the reach, cover is provided by overhanging shrubs, undercut banks, and woody debris. There are two shallow pools in meander bends at the downstream end of the reach. A drop over the downstream end of the culvert under Mail Road creates a barrier to upstream fish passage between the study reach and the headwaters of Locke Brook (fig. 14).

Habitat quality was assessed on three different dates between November 1999 and September 2000 by volunteer and USGS teams using the RBP. Habitat quality was assessed by the USGS on July 12, 2000, at a discharge of about 3.3 ft^3/s (0.76 $ft^3/s/mi^2$), and received a score of 147. Habitat quality was assessed by volunteer teams on July 18, 2000, at a discharge of about 3.4 ft^3/s (0.78 $ft^3/s/mi^2$), and received a score of 154. Habitat quality was assessed by the USGS and volunteers on August 11, 2000, at a discharge of about 4.6 ft^3/s (1.05 $ft^3/s/mi^2$), and received a score of 162. Habitat scores were mostly in the optimal range, but were marginal to suboptimal for pool variability, and suboptimal for channel-flow status and bank-vegetation protection. The reach received scores in the poor range for riparian vegetative zone width because of the removal of vegetation along the stream banks.

When water levels decline enough for the top of the substrate to become exposed, most pocket-water habitat is lost throughout the stream channel, and

A. Riffle, upstream view

B. Riffle, downstream view

Figure 14. Habitat features on Locke Brook at Mail Road (Site L1), Exeter, Rhode Island: (*A*) riffle, upstream view, and (*B*) riffle, downstream view.

habitat quality in undercut banks and beneath overhanging vegetation is poor. In the upstream portions of the reach, the area of shallow-water habitat that extends into emergent vegetation along the stream margins decreases as water levels decrease. Beds of submerged aquatic vegetation provide some habitat at low flows, but the quality of that habitat declines as water depth decreases. At discharges near 3 ft^3/s the channel is close to fully wetted, but the tops of cobbles and boulders are exposed in the riffle. Some edgewater habitats are exposed. The water depths are shallow in velocity-shelter habitat downstream of boulders. Water velocity remains good through beds of submerged aquatic vegetation.

Fisherville Brook at Liberty Church Road (Site F2), Exeter

This reach is about 400 ft downstream of the Liberty Church Road bridge over Fisherville Brook in Exeter. Drainage area to the site is 8.14 mi^2. The site begins several hundred feet downstream of the bridge, and extends about 200 ft downstream from the point where a side channel along the left bank joins the main channel. The reach has a moderate gradient and includes several riffles. Although the stream channel appears to be natural, a side channel on the left bank and an old foundation on a hill near the right bank indicate that the stream upstream of the reach may have been altered historically. The brook in this reach is about 20 ft wide and mostly shaded by trees and overhanging shrubs along the forested banks. The reach is predominantly riffle-and-run habitat with a coarse sand, gravel, and cobble streambed. Cover in the riffle is provided by turbulent stream surfaces and velocity shelters behind cobbles, boulders, and woody debris in the channel. Some of the boulders are covered with aquatic moss, which provides habitat for invertebrates. The streambed also contains some metal and other debris. The downstream portion of the reach has several shallow pools and one long pool which has water depths of about 3 ft during low flow. Cover in the pools is mostly provided by water depth, overhanging shrubs, woody debris, and undercut banks (fig. 15).

Habitat quality was assessed by volunteer and USGS teams using the RBP on November 17, 1999, at a discharge of about 12 ft^3/s (1.47 $ft^3/s/mi^2$). The habitat in the reach received a score of 191, one of the highest scores assigned during the study. Habitat quality was assessed on two other dates and received scores of 184 on July 11, 2000, at a discharge of about 4.8 ft^3/s (0.59 $ft^3/s/mi^2$), and 190 on September 20, 2000, at a discharge of about 9.6 ft^3/s (1.18 $ft^3/s/mi^2$). Habitat scores were mostly in the optimal range. Metrics for velocity-depth regime and channel-flow status were scored suboptimal during July low flows.

A. Riffle, downstream view

B. Riffle, downstream view

Figure 15. Habitat features on Fisherville Brook at Liberty Church Road (Site F2), Exeter, Rhode Island: (*A*) riffle, downstream view, and (*B*) riffle, downstream view.

As water levels drop, the quality of pocket water behind cobbles and boulders decreases. Once water levels reach the bottom of the banks, most undercut bank and exposed root habitat is lost, and the tops of boulders become exposed. When water levels drop enough for the edge of water to pull away from the banks, shelter beneath overhanging shrubs is lost in the riffle-and-run portions of the reach. In the glide-and-pool portions of the reach, the channels are deep and narrow and overhanging shrubs continue to provide cover even at extremely low flows. Under these conditions, however, the quality of glide-and-pool habitat declines because of lowered stream velocities. At discharges near 5 ft^3/s the channel is close to fully wetted. The tops of boulders are exposed in the riffle. Some edgewater habitats are exposed, and overhanging vegetation at the banks provides some cover, but over shallow water.

Fisherville Brook near Pardon Joslin Road (Site F1), Exeter

This reach is about 0.3 mi downstream of Pardon Joslin Road, and downstream of an impoundment on the Rhode Island Audubon Society Fisherville refuge, in Exeter. The drainage area to the site is 4.22 mi^2. The study site is within a low-gradient reach of the river. The channel downstream of the impoundment may have been straightened, or otherwise altered because of its close proximity to the impoundment. The impoundment likely reduces the transport of sediment into the reach from upstream. Ground-water seepage from the remains of a small canal enters the stream from the right bank. The bed of the canal is covered with orange iron-bacteria deposits. A stand of mature hemlock shades the channel throughout the reach. The river is narrow, about 15 ft wide. Woody debris is abundant in the channel. The reach consists of predominantly low-gradient riffle, run, and pool habitats with a coarse sand and gravel streambed. Several large boulders (more than 2 ft in diameter) are scattered throughout the lower portion of the reach. The pools are shallow (less than 1.5 ft) at low flow. Cover in the reach is provided primarily by woody debris and undercut streambanks (fig. 16).

Habitat quality was assessed on two different dates in 1999 and 2000 by volunteer and USGS teams using the RBP. The habitat in the reach received scores between 178 and 189. Habitat scores were mostly in the optimal range.

Undercut bank and exposed-root habitat is lost when water levels drop enough for the edge of the stream to recede from the banks. The channel is narrow, so woody debris that bridges the channel is exposed even at moderate flows. At discharges near 2–3 ft^3/s, water depths are very shallow at the edge of water and in the undercut banks, and the streambed on the sandbar on the inside bend of the meander is exposed.

Summary of Habitat Variability with Flow

Streamflows that provide good habitat in riffles also seem to provide good habitat in nearby run and glide-and-pool habitats. Habitat in riffle reaches is

A. Woody debris, downstream view

B. Run, upstream view

Figure 16. Habitat features on Fisherville Brook near Pardon Joslin Road, (Site F1), Exeter, Rhode Island: (*A*) woody debris, downstream view, and (*B*) run, upstream view.

provided by localized pockets of moderately deep water, velocity shelters behind cobbles and boulders, and by overhanging vegetation along stream margins. These features provide good habitat at streamflows that cover the substrate to depths suitable for fish passage, fully wet the channel bed, and provide water depths along the edges of the channel that are adequate for stream-margin habitat features to be usable. Cover features in run and glide habitats are mostly associated with the stream margins and banks. These features provide good habitat when the streamflow is great enough to fully wet the channel bed, and water depths along the edges of the channel are adequate for the stream-margin habitat features to be usable. In pools and low-gradient wetland reaches of the Usquepaug–Queen River, habitat and cover is provided by stream margin habitat and also by submerged and emergent aquatic vegetation. Water depth alone provides some habitat in pools. Reaches that have a diversity of cover features are more likely to maintain some amount of cover over a wide range of flows. Most of the sites in this study that were unaltered scored relatively high using the RBP during periods of moderate flow, indicating that these sites represent places that have good habitat and could contribute to the health of the river were adequate flows maintained.

In general, habitat availability does not decrease uniformly as flows decline. Large areas of habitat can become unavailable over a small range of discharge as streambeds and stream-margin habitat become exposed. Evaluation of stream habitat at different flows reveals that each type of channel geomorphic unit (riffle, run, glide, or pool) tends to have characteristic changes in habitat in response to declining streamflow. Although the scale of changes in stage in response to declining streamflow is roughly proportional to the drainage area of a site, the process by which habitats are lost in each type of channel geomorphic unit tends to be similar regardless of position within a stream system.

Reaches that have high gradients, such as riffles, undergo rapid changes in habitat availability and quality as flows decline. Riffles and higher-gradient runs that have rectangular or trapezoidal cross sections develop shallow water conditions very quickly as flows decline, and are among the best locations for monitoring the variability of habitat with streamflow. Once decreases in water depth expose the tops of cobble substrate, little depth may remain to provide useful habitat or fish passage. Habitat in low-to-moderate gradient reaches, such as glides and low-gradient runs, is mostly associated with channel margins. Once water levels recede to the base of the stream banks, undercut bank habitat is lost, and the quality of habitat beneath overhanging vegetation is poor because of shallow water depths. When the edge of water recedes from the banks, the habitat provided by most cover features, such as woody debris, overhanging vegetation, undercut banks, and exposed roots, is lost. Large losses of shallow habitat also can occur when flows decline far enough for side channels to become disconnected from the main channel. Water depths in low-gradient reaches, such as pools, generally remain deeper than in moderate-to-high-gradient reaches. As flows decline, overhanging

vegetation on steep banks on the outside bends of pools can provide cover long after the edge of water has receded from the stream banks in other areas of the pool. Other cover features in the channel may provide cover even during very low flows. For example, narrow passages between beds of aquatic vegetation can provide habitat even though adjacent vegetated mid-channel bars are exposed; and scour holes beneath or adjacent to trees that have fallen into the channel may provide moderately deep habitat with some overhead cover even when water depths between pools have become low enough to isolate the pools. However, other factors that are directly or indirectly affected by decreasing flows, such as decreased water velocities and elevated temperatures, may also act to reduce habitat quality during low flows. In general, for reaches of all gradients, as flows decline and habitat becomes unavailable, the quality of remaining habitat also declines.

Stream Temperature

Water-temperature data were collected at eight sites in the Usquepaug–Queen River between June 23 and September 25, 2000 (table 5). To assess the suitability of summer stream temperatures for cold-water fish species, stream temperatures were compared to critical and optimum ranges for brook trout and 7-day moving means of daily maximum stream temperatures were compared to maximum weekly average temperatures (MWAT) and short-term maxima (STM) survival temperatures. Brook trout were selected for the comparisons because of state and local concerns regarding maintenance of brook trout in the Usquepaug–Queen River, and because water temperature is the single most important factor limiting brook trout populations (Picard, 1995).

In general, stream temperatures below 68°F are considered favorable for brook trout. The upper critical range for brook trout is 68–84°F (Elliot, 1994). The upper critical range is the temperature range over which a significant disturbance in the normal behavior of a fish may occur, ranging from cessation of feeding to death. Sustained stream temperatures greater than 77.5°F are generally lethal for brook trout. During prolonged warm periods, populations of brook trout can exist in thermally marginal streams only if sufficient cold-water refugia exist, such as springs or pools that receive cool ground-water discharge. The distribution and abundance of brook trout in relation to temperatures of local coolwater refugia were not measured in this study. Stream temperatures recorded at the study sites likely represent the overall stream temperature, and therefore should be used only to provide a general indication of the suitability of summer stream temperatures for cold-water fish species.

To illustrate differences in stream temperatures between the study sites, the seven-day moving mean of daily maximum stream temperature was calculated for each site and then compared to maximum weekly average temperature (MWAT) and short-term maxima (STM) survival temperature criteria for brook trout (fig. 17).

The maximum temperatures observed were 80.2 and 79.6°F in the headwaters of the Queen River at Route 102 and William Reynolds Road, respectively. The 7-day mean of the daily maximum stream temperatures at these sites was greater than 68°F for all but a few days in mid-September. Stream temperatures at these sites were in the upper critical range for brook trout (over 68°F) for 62 percent of the time at the Route 102 site and 53 percent of the time at the William Reynolds Road site. The warm stream temperatures in the headwaters of the Queen River are possibly caused by the combined effects of the small extent of sand and gravel aquifer in the contributing area to the study sites, the presence of several small impoundments, and the removal of riparian vegetation from some of the reaches.

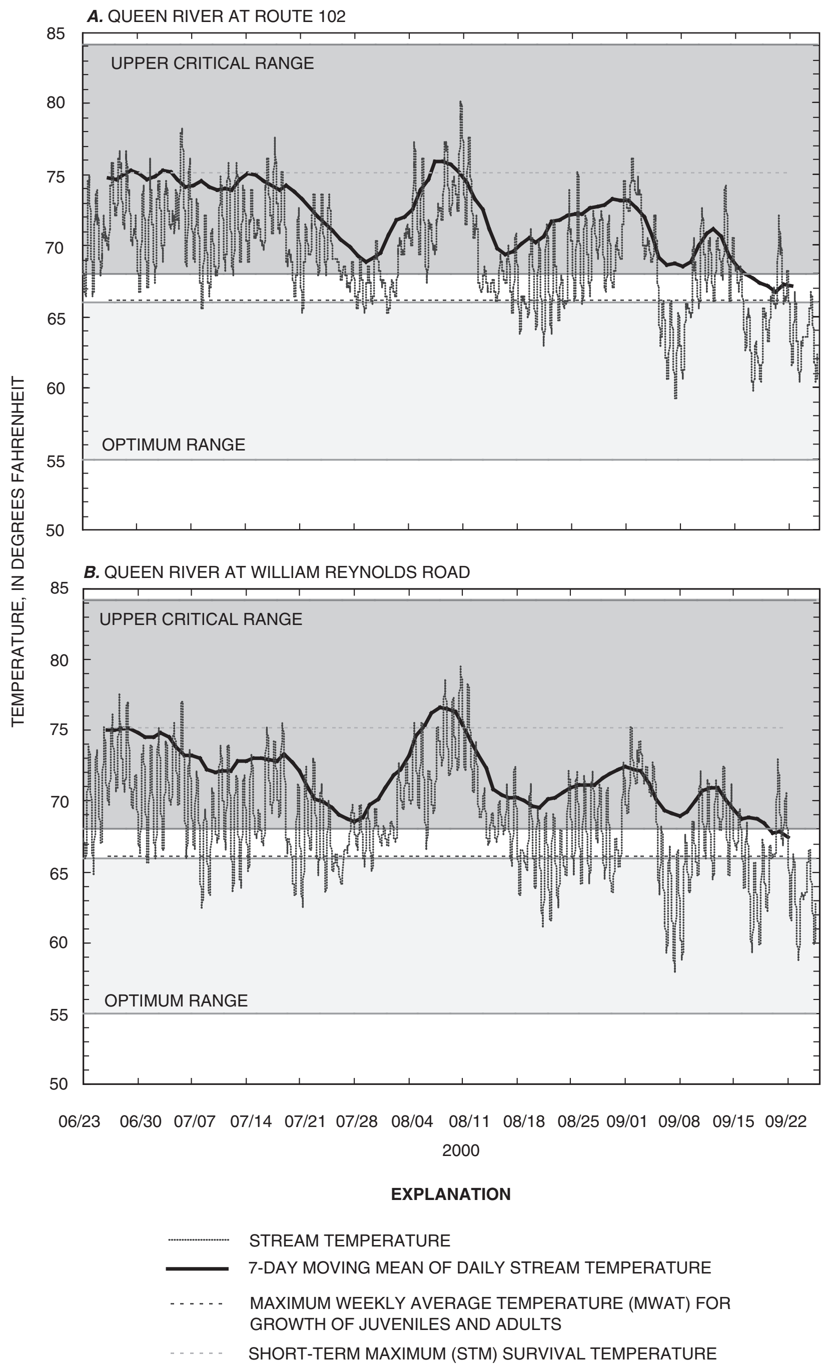

Figure 17. Stream temperature in the Usquepaug–Queen River, Rhode Island, June to September 2000: (*A*) Queen River at Route 102, Exeter, (*B*) Queen River at William Reynolds Road, Exeter, (*C*) Fisherville Brook at Liberty Church Road, Exeter, (*D*) Queen River at Dawley Road, Exeter, (*E*) Queen River at Liberty Road, Exeter, (*F*) Locke Brook at Mail Road, Exeter, (*G*) Usquepaug River at Route 138, South Kingstown, and (*H*) Usquepaug River at Route 2, South Kingstown.

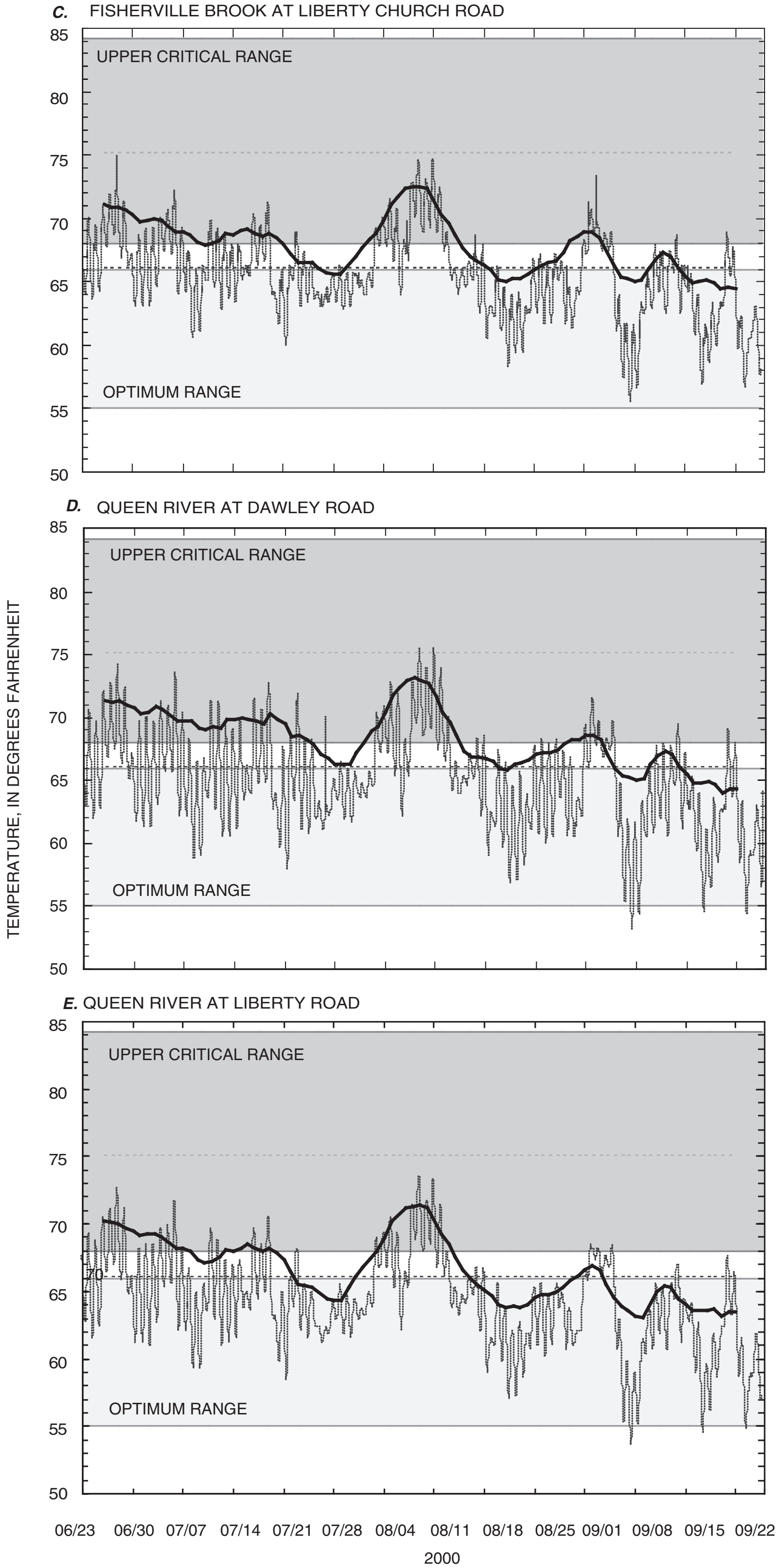

Figure 17. Stream temperature in the Usquepaug–Queen River, Rhode Island, June to September 2000: (*A*) Queen River at Route 102, Exeter, (*B*) Queen River at William Reynolds Road, Exeter, (*C*) Fisherville Brook at Liberty Church Road, Exeter, (*D*) Queen River at Dawley Road, Exeter, (*E*) Queen River at Liberty Road, Exeter, (*F*) Locke Brook at Mail Road, Exeter, (*G*) Usquepaug River at Route 138, South Kingstown, and (*H*) Usquepaug River at Route 2, South Kingstown—*Continued*.

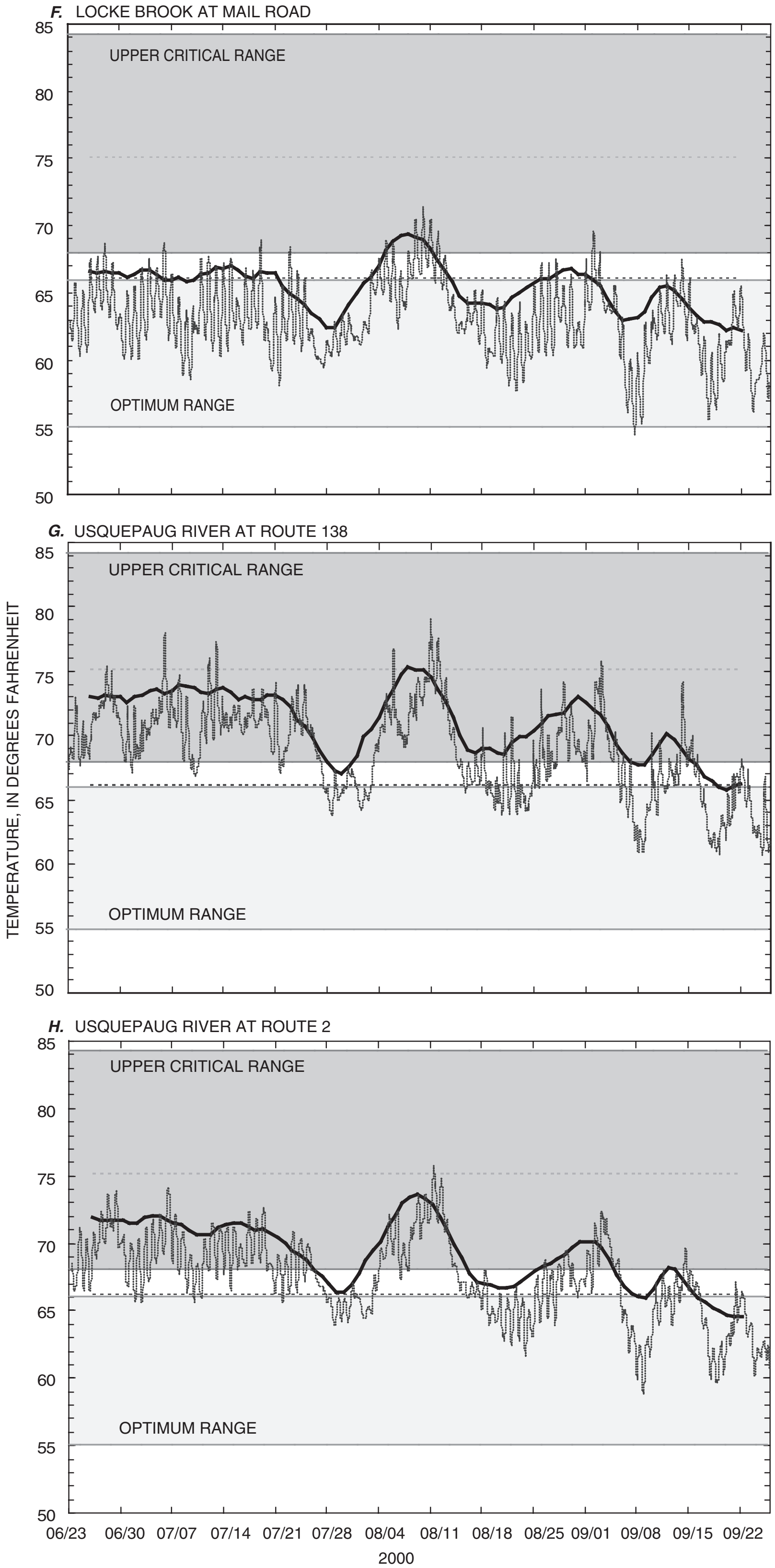

Figure 17. Stream temperature in the Usquepaug–Queen River, Rhode Island, June to September 2000: (*A*) Queen River at Route 102, Exeter, (*B*) Queen River at William Reynolds Road, Exeter, (*C*) Fisherville Brook at Liberty Church Road, Exeter, (*D*) Queen River at Dawley Road, Exeter, (*E*) Queen River at Liberty Road, Exeter, (*F*) Locke Brook at Mail Road, Exeter, (*G*) Usquepaug River at Route 138, South Kingstown, and (*H*) Usquepaug River at Route 2, South Kingstown—*Continued*.

The minimum temperatures observed were 53.2 and 53.7°F for the mainstem Queen River at Dawley Road and at Mail Road, respectively. Stream temperatures at these sites were in the upper critical range for brook trout (over 68°F) for 22 percent of the time at the Dawley Road site and 14 percent of the time at the Mail Road site. Most of the time, however, stream temperatures in this reach are near the upper end of the optimum range of temperatures for brook trout, between about 62 and 67°F. The Dawley Road site had the greatest range of diel temperatures during the study period, about 9.5°F, and averaging about 6.1°F. Upstream of Dawley Road, the mainstem Queen River receives cool-water discharge from Fisherville Brook. Downstream of Mail Road, the Queen River receives additional cold-water inputs from Locke Brook. The cooler stream temperatures in this segment of the mainstem Queen River are possibly caused by the combined effects of ground-water discharge to the stream, shading of the stream channel, and the input of cool water from tributaries.

Data collected at the Route 138 study site show that water temperatures increase after the water passes through Glen Rock Reservoir, creating stream temperatures in the Usquepaug River that are marginal to poor for brook trout. Water temperatures in the Usquepaug River at Route 138 are warmer by about 6°F in comparison to the mainstem Queen River upstream. Stream temperatures at these sites were in the upper critical range for brook trout (over 68°F) for 59 percent of the time at the Route 138 site and 42 percent of the time at the Route 2 site. The Route 2 site had the smallest range of diel temperatures during the study period, about 4.7°F, and averaging about 3.3°F. Stream temperatures in the Usquepaug River at Route 2 are slightly lower than those at Route 138 possibly because of ground-water inputs to the river and shading of the stream channel.

The temperature of stream water can increase as the amount of ground water discharging to a stream is reduced (Baevsky, 1991; Stark and others, 1994; Picard, 1995). Decreased stream discharge also results in a smaller thermal mass that would be more susceptible to warming from solar radiation. Consequently, further reductions in stream discharge or increases in ground-water withdrawals could increase stream temperatures and thus degrade the habitat for brook trout in summer. Although this study did not determine how reservoirs and current water-withdrawal and land-use practices may be affecting stream temperatures, the stream temperatures in the Usquepaug River and Queen River headwaters were marginal for brook trout in the summer of 2000, and cold-water fish communities that exist in these reaches would appear to have little tolerance for temperature increases that could be created by increased surface or well-water withdrawals, or the inputs from stormwater discharges or impoundment overflows.

Fish-Community Assessment

Fish data collected by the Rhode Island Division of Fisheries and Wildlife in 1998 and the USEPA in 2000 were combined and then grouped into mainstem and tributary datasets for analysis (table 6). The mainstem grouping included all samples from the Usquepaug River and samples from the Queen River downstream of the junction of the Queen River with Fisherville Brook. The tributary grouping included all samples from tributaries and from the headwaters of the Queen River upstream of the junction of the Queen River with Fisherville Brook.

In 1998 and 2000, 811 fish of 18 different species were collected at 5 sites on the mainstem. The fish communities in the mainstem were dominated by Eastern brook trout, redfin pickerel, tesselated darter, American eel, white sucker, and fallfish, composing by number 25, 17, 15, 10, 9, and 9 percent of the mainstem samples, respectively. The remaining 12 species each made up less than 5 percent of the total number of fish collected. In the tributaries, 1,224 fish of 14 different species were collected at 13 sites. Eastern brook trout, Atlantic salmon, and fallfish were the most numerous, composing by number, 56, 27, and 5 percent of the tributary samples, respectively. The remaining 11 species each made up less than 5 percent of the total number of fish collected.

In accordance with habitat-use classifications developed by Bain (U.S. Geological Survey, written commun., 2000), fish species sampled in the Usquepaug–Queen River were divided into one of three macrohabitat classes: macrohabitat generalists, fluvial dependents, and fluvial specialists (table 7). Atlantic salmon, which are stocked, were not included in the analysis. The RIDFW and USEPA data did not include length-frequency information which could have been used to distinguish native from stocked brook trout, so all brook trout were included in the analysis. Fish in the Usquepaug–Queen River mainstem consisted of 52

Table 6. Number of each species and percent of total number of fish collected in the mainstem and tributaries of the Usquepaug–Queen River, Rhode Island, by the U.S. Environmental Protection Agency New England Regional Laboratory in 2000 and the Rhode Island Division of Fish and Wildlife in 1998

[**Mainstem:** Usquepaug River and Queen River downstream of Fisherville Brook. **Tributaries:** Tributaries to the Queen River and the headwaters of the Queen River upstream of Fisherville Brook. **Species**: Species are ranked by percent of total. **Percent**: Percent of the total number of fish collected for the mainstem and for the tributaries for each species]

Species	Number collected	Percent	Species	Number collected	Percent
Mainstem			**Tributaries**		
Brook Trout	201	25	Brook Trout	686	56
Redfin Pickerel	135	17	Atlantic Salmon	333	27
Tesselated Darter	121	15	Fallfish	60	5
American Eel	77	10	White Sucker	53	4
Fallfish	74	9	Redfin Pickerel	38	3
White Sucker	74	9	Swamp Darter	12	1
Pumpkinseed	34	4	American Eel	11	<1
Atlantic Salmon	30	4	Brown Bullhead	7	<1
Bluegill	15	2	Largemouth Bass	6	<1
Golden Shiner	14	2	Bluegill	6	<1
Yellow Perch	10	1	Golden Shiner	5	<1
Brown Bullhead	5	<1	Banded Sunfish	4	<1
Largemouth Bass	5	<1	Pumpkinseed	2	<1
Chain Pickerel	5	<1	Common Shiner	1	<1
Creek Chubsucker	5	<1	Blacknose Dace	0	0
Banded Sunfish	3	<1	Tesselated Darter	0	0
Blacknose Dace	2	<1	Creek Chubsucker	0	0
Bridal Shiner	1	<1	Chain Pickerel	0	0
Common Shiner	0	<1	Yellow Perch	0	0
Swamp Darter	0	0	Bridal Shiner	0	0
All species	811	100	All species	1,224	100

percent fluvial-specialist, 9 percent fluvial-dependent, and 39 percent macrohabitat-generalist species (fig. 18). Fish in tributaries and headwaters of the Queen River consisted of 85 percent fluvial-specialist, 6 percent fluvial-dependent, and 9 percent macrohabitat-generalist species.The fish-community composition of mainstem rivers typically consists of lower percentages of fluvial species than the tributaries (M.B. Bain, USGS, oral commun., 2002).

Historical fish data collected between 1962 and 1965 (Guthrie and others, 1973) were reviewed to compare the fish-community composition of the Usquepaug–Queen River to recent fish data, collected by the Rhode Island Division of Fisheries and Wildlife in 1998 and the USEPA in 2000. The comparison showed that the 1998–2000 fish collection contained five macrohabitat generalist species not collected in 1962–65 (bluegill, brown bullhead, golden shiner, pumpkinseed, and yellow perch) along with one fluvial specialist (Atlantic salmon, which is stocked). Brown trout (stocked), was the only species present in the historical data that was not detected in the 1998 and 2000 samples.

Habitat-use classifications for the mainstem Usquepaug–Queen fish community were compared to habitat-use classifications for target fish communities developed for the Quinebaug River (Bain and Mexler, 2000), and Ipswich River (Ipswich River Fisheries Restoration Task Group, 2002). Target fish communities are model fish communities that have been defined to be appropriate for a natural river. The Quinebaug target fish community can be used as a general guide of what is considered a healthy fish community for large inland streams and small rivers in

Table 7. Scientific names and habitat-use classifications of fish in the Usquepaug–Queen River Basin, Rhode Island

[**Macrohabitat:** FD, fluvial dependent; FS, fluvial specialist; MG, macrohabitat generalist]

Common name	Genus	Species	Macro-habitat
American Eel	*Anguilla*	*rostrata*	MG
Atlantic Salmon	*Salmo*	*salar*	FS
Banded Sunfish	*Enneacanthus*	*obesus*	MG
Blacknose Dace	*Rhinichthys*	*atratulus*	FS
Bluegill	*Lepomis*	*macrochirus*	MG
Bridle Shiner	*Notropis*	*bifrenatus*	MG
Brook Trout	*Salvelinus*	*fontinalis*	FS
Brown Bullhead	*Ameiurus*	*nebulosus*	MG
Chain Pickerel	*Esox*	*niger*	MG
Common Shiner	*Luxilus*	*cornutus*	FD
Creek Chubsucker	*Erimyzon*	*oblongus*	FS
Fallfish	*Semotilus*	*corporalis*	FS
Golden Shiner	*Notemigonus*	*crysoleucas*	MG
Largemouth Bass	*Micropterus*	*salmoides*	MG
Pumpkinseed	*Lepomis*	*gibbosus*	MG
Redfin Pickerel	*Esox*	*americanus*	MG
Swamp Darter	*Etheostoma*	*fusiforme*	MG
Tesselated Darter	*Etheostoma*	*olmstedi*	FS
White Sucker	*Catostomus*	*commersoni*	FD
Yellow Perch	*Perca*	*flavescens*	MG

Southern New England (Bain and Mexler, 2000). The Ipswich target fish community is used to show what is considered a healthy fish community for a small coastal river. Fish in the Quinebaug target fish community had a population consisting of 55 percent fluvial specialists, 27 percent fluvial dependents, and 18 percent macrohabitat generalists (fig. 19). Fish in the Ipswich target fish community had a population consisting of 49 percent fluvial specialists, 19 percent fluvial dependents, and 32 percent macrohabitat generalists. Although a target fish community for the Usquepaug–Queen River has not yet been developed, comparisons to the Quinebaug and Ipswich target fish communities indicate that, for the sites analyzed in this report, the species composition of the mainstem Usquepaug–Queen River appears to have percentages of fluvial species that are near the ranges that could be expected.

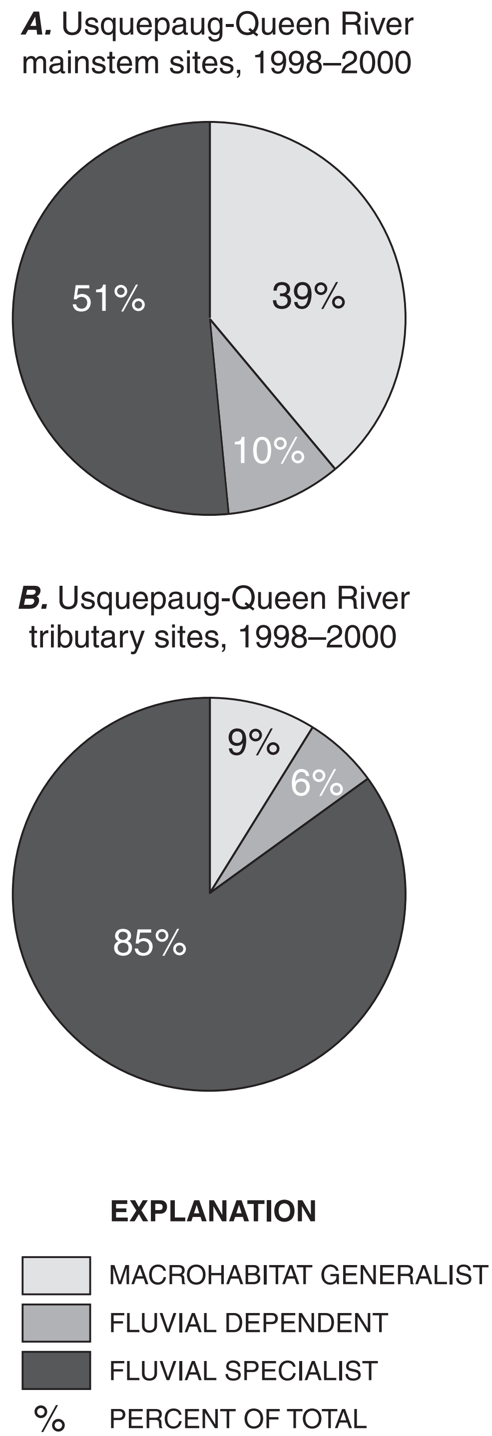

Figure 18. Fish species habitat-use classifications for the Usquepaug–Queen River, Rhode Island: (*A*) mainstem sites, 1998–2000, and (*B*) tributary sites, 1998–2000.

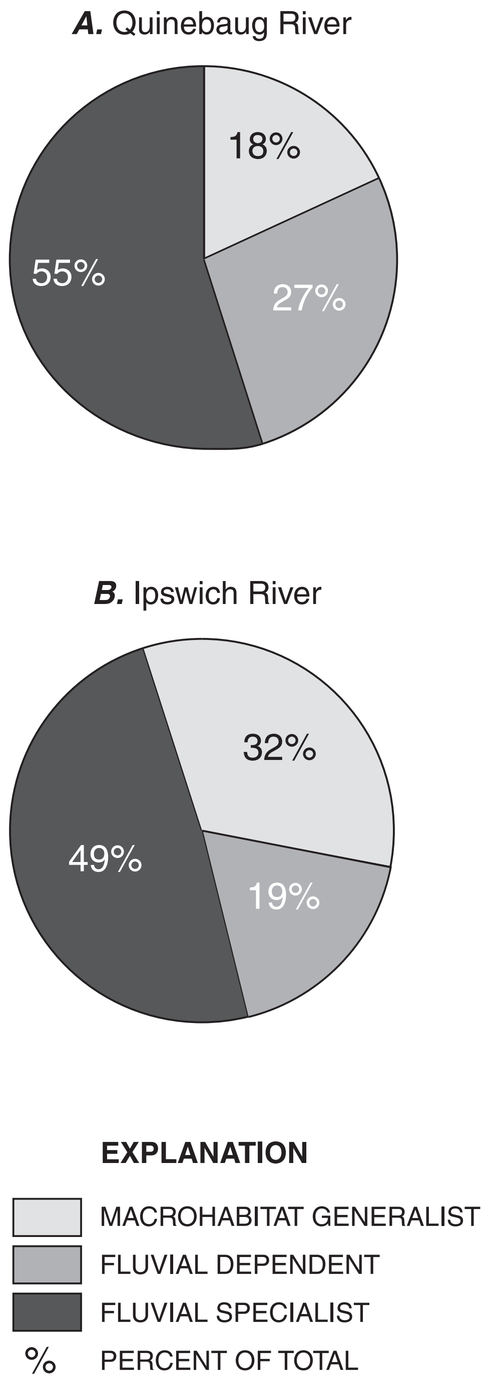

Figure 19. Target fish communities for the: (*A*) Quinebaug River, Massachusetts, and (*B*) Ipswich River, Massachusetts.

STREAMFLOW REQUIREMENTS FOR HABITAT PROTECTION

One diagnostic and four standard-setting methods were used to develop summer streamflow requirements for the Usquepaug–Queen River. The RVA, Tennant, and ABF methods require streamflow data from gaged sites, whereas the Wetted-Perimeter and R2Cross methods require surveys of channel cross sections and water-surface slopes at critical riffle sites, and simulation of stage, discharge, wetted-perimeter, velocity, depth, and other hydraulic criteria used for determination of streamflow requirements.

Streamflow requirements were calculated by means of the RVA, Tennant, and ABF methods on the basis of flow records from the Usquepaug River at Usquepaug gaging station (01117420). Comparisons were made to streamflow requirements determined from the Wood River near Arcadia (01117800) and Beaver River near Usquepaug (01117468) gaging stations, and to other gaging stations in southern New England. Streamflow requirements were calculated by the Wetted-Perimeter and R2Cross methods from field measurements at seven riffles (table 5). Three of these sites are on the Usquepaug–Queen River mainstem, and four are on the Fisherville Brook and Locke Brook tributaries and in the Queen River headwaters. The mainstem sites are located on the Usquepaug River near Laurel Lanes Golf Course in South Kingstown (U2), the Usquepaug River near Route 138 in South Kingstown (U1), and the Queen River near Dawley Road in Exeter (Q5). The tributary sites are located on the Queen River at William Reynolds Road (Q3), Fisherville Brook near Liberty Church Road (F2), Fisherville Brook near Pardon Joslin Road (F1), and Locke Brook near Mail Road in Exeter (F1). These sites were chosen for determination of streamflow requirements for habitat protection because of their sensitivity to low flows. During declining flows, these riffles are among the first reaches to show habitat losses.

Site descriptions and data used for development and calibration of the WinXS Pro and HEC-RAS models are given in Appendix 1, along with the hydraulic criteria (stage, average depth, average velocity, and percent bank-full wetted perimeter) determined by the models for a range of discharges.

Indicators of Hydrologic Alteration and Range of Variability Approach

Results of the IHA analysis from the Usquepaug River near Usquepaug gaging station (01117420) showing mean-monthly discharge for the period 1976–2000, normalized to drainage area, are shown in figure 20. The pattern of mean-monthly discharge shows flows generally increasing from October through March or April. Mean monthly flows generally decline from March or April through September. The low-flow period extends from July through October, with the lowest monthly mean in September.

Streamflows from the Usquepaug River near Usquepaug gaging station (01117420) were compared to streamflows from two nearby streamflow-gaging stations that also are in the Pawcatuck River Basin: Beaver River near Usquepaug, RI (01117468), and Wood River near Arcadia, RI (01117500). The drainage area of the Usquepaug River gage (36.1 mi^2) is almost equal to the area for the Wood River gage (35.2 mi^2), but is considerably larger than the area for the Beaver River gage (8.87 mi^2). The Beaver and Wood Rivers have few water withdrawals upstream of the gaging stations and represent mostly unregulated conditions. Streamflows in the Usquepaug River are relatively unregulated in fall, winter, and spring.

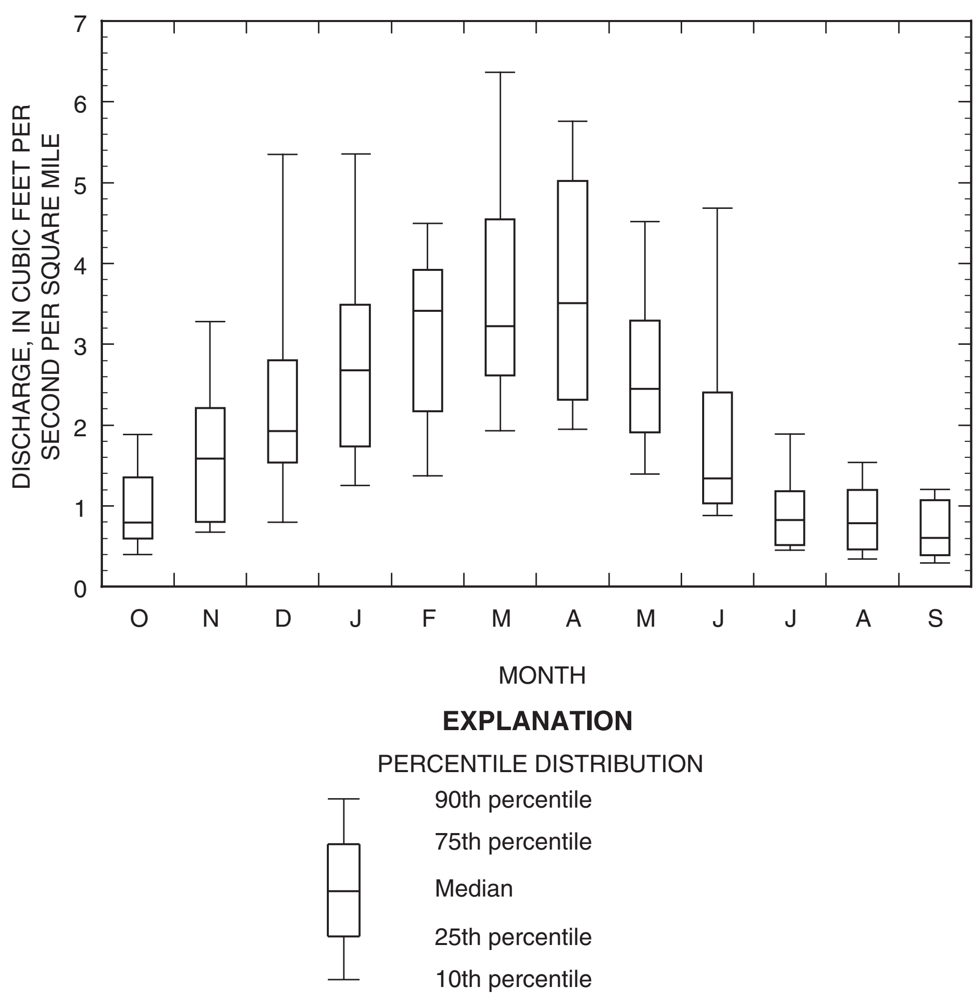

Figure 20. Distribution of monthly mean flow, Usquepaug River near Usquepaug, Rhode Island, gaging station (01117420).

The range of variability in monthly mean streamflows, annual n-day low-flow statistics, and additional measures of flow used by the RVA as flow-management targets are given in tables 8, 9, and 10 for the Usquepaug, Beaver, and Wood River gaging stations for the 25-year period from 1976–2000. Because of water withdrawals upstream of the Usquepaug gaging station between May and October, monthly means for the summer months, annual n-day low flows, and other low-flow statistics are lower than they would be were there no withdrawals. Nonetheless, these streamflow statistics can be useful indicators of the magnitude of streamflows recommended as flow-management targets by the RVA method. Once the HSPF model under development for the Usquepaug–Queen Basin is complete, streamflows representing no-withdrawal conditions in the Usquepaug–Queen River can be simulated, and the RVA streamflow statistics can be recalculated. The recalculated mean monthly flows for the summer months and low-flow statistics for the Usquepaug gaging station would be expected to be higher than those calculated from current conditions.

Maintenance of streamflow variability throughout the year and between years is important for a healthy ecosystem (Poff and others, 1998; Hill and others, 1991). Water withdrawals or regulation that cause streamflows to be maintained at a minimum level over an extended period of time are detrimental to a healthy ecosystem (Instream Flow Council, 2002). The RVA recommends maintaining flows within a range of streamflow that is similar to the natural flow regime of the stream. The target range is defined by the 25th to 75th percentiles for monthly mean flows, and for several ecologically relevant flow statistics such as the 1-, 3-, 7-, 30-, and 90-day annual low-flows (n-day low-flow periods), the number of days that the daily discharge is below the 25th percentile, and the number of days of zero flow. In the summer months, the streamflow at the lower limit of this target range (25th percentile) for some of these flow statistics may be lower than the streamflow requirements for habitat protection determined by standard-setting methods. The RVA does not recommend maintaining flows exclusively at or near the level of the lower percentile, however, and restricts the magnitude, timing, frequency, and duration of low flows by requiring streamflow to be within the 25th- to 75th-percentile range for each of 33 flow statisitics. The ability to maintain streamflows within the RVA flow-management target ranges would require active and coordinated management controls, particularly during late summer when flows are naturally low.

Table 8. Hydrologic data for the 1976 to 2000 period for the gaging station on the Usquepaug River near Usquepaug (01117420), Rhode Island

Period or condition	Percentile					
	10th	25th	50th	75th	90th	(75-25)/50
Magnitude of monthly mean discharge (cubic feet per second)						
October	14.3	21.5	28.8	50.0	69.8	1.0
November	24.0	28.8	57.3	80.7	117.3	.9
December	28.9	54.5	69.4	100.9	190.4	.7
January	45.6	60.7	96.7	128.5	190.1	.7
February	49.0	78.0	123.1	142.0	164.2	.5
March	70.7	94.0	116.4	165.6	230.4	.6
April	67.6	81.3	126.8	183.3	207.7	.8
May	50.3	68.8	88.3	119.2	164.0	.6
June	31.7	36.7	48.4	87.0	168.3	1.0
July	16.2	19.6	29.9	43.4	68.3	.8
August	12.0	16.0	28.4	43.4	55.5	1.0
September	11.4	14.1	21.7	39.1	44.8	1.2

Table 8. Hydrologic data for the 1976 to 2000 period for the gaging station on the Usquepaug River near Usquepaug (01117420), Rhode Island—*Continued*

Period or condition	Percentile					
	10th	25th	50th	75th	90th	(75-25)/50
Magnitude and duration of annual discharge conditions (cubic feet per second)						
1-day minimum	3.5	5.2	11.0	14.0	18.4	0.8
3-day minimum	3.9	5.4	11.7	14.8	19.2	.8
7-day minimum	5.0	6.9	12.6	16.4	20.8	.8
30-day minimum	7.9	10.5	17.1	20.4	26.2	.6
90-day minimum	13.2	16.3	20.7	33.6	38.8	.8
1-day maximum	223.6	270.0	373.0	564.5	664.6	.8
3-day maximum	195.9	227.8	321.3	484.3	597.7	.8
7-day maximum	150.7	194.6	255.7	365.6	455.9	.7
30-day maximum	102.8	144.6	185.3	246.6	278.0	.6
90- day maximum	96.0	111.6	145.5	164.0	209.3	.4
Zero discharge days	0	0	0	0	0	0
7-day minimum/mean annual discharge	.1	.1	.1	.2	.3	1.0
Timing of annual discharge extremes (Julian day)						
Date of minimum 1-day discharge	205.6	225.5	254.0	275.0	275.8	0.1
Date of maximum 1-day discharge	10.8	28.5	83.0	111.5	156.0	.2
Frequency and duration of high and low pulses						
Times that daily discharge is less than the 25th percentile of daily discharge (count)	3.0	5.0	8.0	9.5	11.4	0.6
Days that daily discharge is less than the 25th percentile	4.7	6.0	10.0	14.9	20.1	.9
Times that daily discharge is greater than the 75th percentile of daily discharge (count)	3.0	5.0	9.0	11.0	13.0	.7
Days that daily discharge is greater than the 75th percentile	3.2	5.8	11.0	14.0	26.9	.7
Rate and frequency of hydrograph changes						
Mean of all positive differences between consecutive daily discharges (rise rate)	12.4	15.9	17.7	24.9	31.2	0.5
Mean of all negative differences between consecutive daily discharges (fall rate)	-13.2	-10.6	-7.9	-7.1	-5.8	-.4
Number of reversals	86.6	92.5	97.0	102.0	104.2	.1

Table 9. Hydrologic data for the 1976 to 2000 period for the gaging station Beaver River near Usquepaug (01117468), Rhode Island

Period or condition	Percentile					
	10th	25th	50th	75th	90th	(75-25)/50
Magnitude of monthly mean discharge (cubic feet per second)						
October	3.29	4.7	6.72	12.38	19.16	1.14
November	6.01	7	13.95	24.08	34.62	1.22
December	7.33	13.66	20.11	30.48	50.68	.84
January	11.17	17.56	27.16	33.94	50.41	.6
February	12.78	20.96	31.82	37.93	43.29	.53
March	22.45	26.52	32.94	44.37	57.37	.54
April	20.05	23.55	36.9	46.02	55.77	.61
May	15.25	19.74	24.84	35.37	45.84	.63
June	9.45	11.55	14.53	25.95	45.99	.99
July	4.7	5.8	8.68	12.34	22.03	.75
August	2.72	4.32	7.38	11.43	14.64	.96
September	2.82	3.63	5.92	9.18	11.67	.94
Magnitude and duration of annual discharge conditions (cubic feet per second)						
1-day minimum	1.36	1.8	2.7	3.1	4.44	0.48
3-day minimum	1.42	1.8	2.7	3.23	4.51	.53
7-day minimum	1.59	2.09	2.91	3.91	4.84	.63
30-day minimum	2.07	2.62	4.23	5.38	6.73	.65
90-day minimum	3.23	4.44	5.82	8.71	10.46	.73
1-day maximum	65.6	77	109	149	236.2	.66
3-day maximum	53.47	67.17	90.67	121.67	178.4	.6
7-day maximum	41.14	51.57	71	93.14	136.17	.59
30-day maximum	29.38	38.73	49	63.1	81.34	.5
90- day maximum	26.09	31.32	39.36	45.12	52.68	.35
Zero discharge days	0	0	0	0	0	0
7-day minimum/mean annual discharge	.08	.1	.13	.2	.28	.79
Timing of annual discharge extremes (Julian day)						
Date of minimum 1-day discharge	220.6	247	267	275	279.8	0.08
Date of maximum 1-day discharge	327.2	24.5	71	110.5	155	.23
Frequency and duration of high and low pulses						
Times that daily discharge is less than the 25th percentile of daily discharge (count)	2.8	6	7	10.5	11.8	0.64
Days that daily discharge is less than the 25th percentile	3.79	5.97	8.88	14.58	19.39	.97
Times that daily discharge is greater than the 75th percentile of daily discharge (count)	4	7	10	12	17	.5
Days that daily discharge is greater than the 75th percentile	2.48	4.97	9.5	11.63	18.56	.7

Table 9. Hydrologic data for the 1976 to 2000 period for the gaging station Beaver River near Usquepaug (01117468), Rhode Island—*Continued*

Period or condition	Percentile					
	10th	25th	50th	75th	90th	(75-25)/50
Rate and frequency of hydrograph change						
Mean of all positive differences between consecutive daily discharges (rise rate)	5	5.89	7.12	8.14	11.53	0.32
Mean of all negative differences between consecutive daily discharges (fall rate)	-4	-3.11	-2.68	-2.27	-1.84	-.31
Number of reversals	74.6	84	92	102	110.4	.2

Table 10. Hydrologic data for the 1976 to 2000 period for the gaging station Wood River near Arcadia (01117800), Rhode Island

Period or condition	Percentile					
	10th	25th	50th	75th	90th	(75-25)/50
Magnitude of monthly mean discharge (cubic feet per second)						
October	13.1	19.33	29.53	57.96	87.5	1.31
November	29.18	37.37	62.87	95.81	118.73	.93
December	38.4	56.93	78.44	123.12	194.08	.84
January	46.94	66.7	107.76	123.09	196.53	.52
February	56.48	83.45	112.14	145.11	154.84	.55
March	79.94	99.8	129.02	172.19	208.16	.56
April	80.5	85.82	129.97	156.75	224.38	.55
May	55.06	68.4	86.71	118.02	145.65	.57
June	31.1	33.48	45.55	69.14	128.28	.78
July	12.92	17.77	27.81	36.72	60.35	.68
August	9.87	17.43	25.44	50.68	63.08	1.31
September	9.82	16.69	21.77	32.59	44.8	.73
Magnitude and duration of annual discharge conditions (cubic feet per second)						
1-day minimum	5.05	6.93	8.95	13	16.5	0.68
3-day minimum	5.38	7.49	9.27	14.08	17	.71
7-day minimum	5.73	8.29	10.76	16.39	18.29	.75
30-day minimum	7.16	10.92	14.74	19.71	24.8	.6
90-day minimum	11.67	16.08	25.43	30.85	42.77	.58
1-day maximum	253.5	295	378.5	538.25	719.5	.64
3-day maximum	213.17	258.58	318.17	462.33	598	.64
7-day maximum	162.71	205.61	242.14	375.5	463.57	.7
30-day maximum	119.38	135.43	187.85	226.45	296	.48
90- day maximum	96.22	116.29	147.57	163.29	195.97	.32
Zero discharge days	0	0	0	0	0	0
7-day minimum/mean annual discharge	.08	.1	.16	.19	.24	.61

Table 10. Hydrologic data for the 1976 to 2000 period for the gaging station Wood River near Arcadia (01117800), Rhode Island—*Continued*

Period or condition	Percentile					
	10th	25th	50th	75th	90th	(75-25)/50
Timing of annual discharge extremes (Julian day)						
Date of minimum 1-day discharge	209	224.75	252	273.5	284	0.13
Date of maximum 1-day discharge	351	24.75	70.5	104	124.5	.22
Frequency and duration of high and low pulses						
Times that daily discharge is less than the 25th percentile of daily discharge (count)	4.5	5	7.5	9	11	0.53
Days that daily discharge is less than the 25th percentile	5.61	7.09	10.86	14.94	23.53	.72
Times that daily discharge is greater than the 75th percentile of daily discharge (count)	3.5	6.25	9.5	12.75	15.5	.68
Days that daily discharge is greater than the 75th percentile	3.26	6.19	9.92	13.9	17.94	.78
Rate and frequency of hydrograph changes						
Mean of all positive differences between consecutive daily discharges (rise rate)	12.44	17.89	21.11	31.34	36.12	.64
Mean of all negative differences between consecutive daily discharges (fall rate)	-13.02	-10.67	-7.75	-6.83	-4.96	-.5
Number of reversals	82	88	96.5	102	106.5	.15

Tennant Method

Streamflow requirements were calculated by the Tennant method from streamflow data from the gaging station on the Usquepaug River near Usquepaug (01117420) for the period 1958–2000. The mean annual flow (Q_{MA}), the flow statistic used by the Tennant method, is 76.7 ft^3/s at the Usquepaug gage (Socolow and others, 2000). Streamflow requirements determined by the Tennant method are given in table 11. The 40-, 30-, and 10-percent Q_{MA} values for the Usquepaug River which represent good, fair, and poor habitat conditions according to Tennant (1976), normalized for drainage area, are 0.85, 0.64, and 0.21 ft^3/s/mi^2, respectively. The 25-percent Q_{MA} value, which is used to determine summer streamflow requirements in the Canadian Atlantic Provinces (Dunbar and others, 1998), is 0.53 ft^3/s/mi^2.

For comparison, Tennant streamflow requirements were also determined for 16 nearby gaging stations in Rhode Island, Connecticut, and Massachusetts with at least 20 years of good record. The average 40-, 30-, and 10-percent Q_{MA} values for these sites were very similar to those determined for the Usquepaug River and were 0.80, 0.60, and 0.20 ft^3/s/mi^2, respectively. The 25-percent Q_{MA} used to set streamflow requirements in the Canadian Atlantic Provinces averaged 0.50 ft^3/s/mi^2 (table 12). The 40-, 30-, and 10-percent Q_{MA} Tennant streamflow requirements for the nearby Wood River were almost identical to those determined for the Usquepaug River and were 0.87, 0.65, and 0.22 ft^3/s/mi^2. The 40-, 30-, and 10-percent Tennant streamflow requirements for the nearby Beaver River were slightly higher and were 0.96, 0.72, and 0.24 ft^3/s/mi^2, respectively. The latter two basins are generally considered to be unregulated.

Table 11. Summer streamflow requirements determined by the Tennant method for the gaging station Usquepaug River near Usquepaug (01117420), Rhode Island

[Q_{MA}, mean annual flow; ft³/s, cubic feet per second; ft³/s/mi², cubic feet per second per square mile; <, less than]

Aquatic-habitat condition for small streams	Percentage of Q_{MA}, April–September	Streamflow requirements	
		ft³/s	ft³/s/mi²
Flushing flows	200	153.4	4.25
Optimum range	60–100	46–76.7	1.28–2.13
Outstanding	60	46	1.28
Excellent	50	38.4	1.06
Good	40	30.7	0.85
Fair	30	23.0	0.64
Poor	<10	<7.7	<0.21
Severe degradation	<10	<7.7	<0.21

Table 12. Streamflow requirements determined by the Tennant Method for 16 gaging stations in southern New England

[Q_{MA}, Mean annual flow; ft³/s, cubic feet per second; ft³/s/mi², cubic feet per second per square mile; mi², square mile]

Gaging station	Drainage area (mi²)	Q_{MA} (ft³/s)	Period of record (years)	Q_{MA} (ft³/s/mi²)	0.4 Q_{MA} (ft³/s/mi²)	0.3 Q_{MA} (ft³/s/mi²)	0.25 Q_{MA} (ft³/s/mi²)	0.1 Q_{MA} (ft³/s/mi²)
Beaver River (01117468)	8.87	21.3	24	2.40	0.96	0.72	0.60	0.24
Wood River near Arcadia (01117800)	35.2	76.7	34	2.18	.87	.65	.54	.22
Wood River near Hope Valley (01118000)	72.4	156	58	2.15	.86	.65	.54	.22
Pendleton Hill Brook (01118300)	4.02	8.62	40	2.14	.86	.64	.54	.21
Chipuxet River (01117350)	9.99	21.3	27	2.13	.85	.64	.53	.21
Indian Head River (01105730)	30.3	63.1	33	2.08	.83	.62	.52	.21
Hunt River (01117000)	22.9	46.8	59	2.04	.82	.61	.51	.20
Old Swamp River (01105600)	4.5	9.18	33	2.04	.82	.61	.51	.20
Pawcatuck River at Wood R. Jct (01117500)	100	196	58	1.96	.78	.59	.49	.20
Pawcatuck River at Westerly (01118500)	295	577	58	1.96	.78	.59	.49	.20
Branch River (01111500)	91.2	175	59	1.92	.77	.58	.48	.19
Little River (01123000)	30	57	47	1.90	.76	.57	.48	.19
Salmon River (01193500)	100	186	70	1.86	.74	.56	.47	.19
Mount Hope River (01121000)	28.6	52.3	58	1.83	.73	.55	.46	.18
Moshassuck River (01114000)	23.1	40.6	36	1.76	.70	.53	.44	.18
Broad Brook (01184490)	15.5	24.7	38	1.59	.64	.48	.40	.16
Averages				2.00	0.80	0.60	0.50	0.20

New England Aquatic-Base-Flow Method

Streamflow requirements for the Usquepaug River obtained with the ABF method stipulate default streamflows of 0.5 $ft^3/s/mi^2$ in summer, 1.0 $ft^3/s/mi^2$ in fall and winter, and 4.0 $ft^3/s/mi^2$ in spring. The ABF method requires these default streamflows to be used rather than streamflows determined from the ABF median of monthly-mean flows for rivers that are regulated and have drainage areas of less than 50 mi^2. These drainage-area criteria and free-flowing requirements were intended to provide consistent resource-protective (conservative) results (Lang, 1999). However, even with current levels of water withdrawals, the summer streamflows in the Usquepaug River are frequently greater than the 0.5 $ft^3/s/mi^2$ ABF default summer-streamflow requirement. The median of monthly mean flows for August for the Usquepaug River near Usquepaug (01117420) gaging station was 28.35 ft^3/s, or 0.79 $ft^3/s/mi^2$, for the 1976–2000 period. The high base flows in the Usquepaug River are likely caused by large amounts of ground-water discharge (Dickerman, 1997) from sand and gravel aquifers in the Usquepaug–Queen River Basin.

For purposes of comparison, the medians of monthly-mean flows for August were also calculated for nearby gaging stations on the Wood and Beaver Rivers. These gaging stations were selected because they are within the same drainage basin (Pawcatuck River Basin), and have minimal to no water withdrawals above the gage. Normalized for drainage area, the August median streamflow for the Usquepaug–Queen River, (0.79 $ft^3/s/mi^2$) is similar in magnitude to the Beaver River (0.83 $ft^3/s/mi^2$) and Wood River (0.72 $ft^3/s/mi^2$). The Wood River likely has a lower median of monthly mean flows for August, normalized for drainage area, than the Usquepaug River because it has a smaller area of sand and gravel as a percentage of drainage area (about 24 percent) than the Usquepaug–Queen River Basin (about 35 percent) (Cervione and others, 1993).

Monthly mean flows for August at the Usquepaug River stream-gaging station were also compared to those at nearby stream gages in Rhode Island, Connecticut, and Massachusetts. A plot of the distribution of August mean flow for the 1976–2000 period for 10 southern New England gaging stations (fig. 21) indicates that, even with water withdrawals, the Usquepaug River has one of the highest values for the median of monthly mean flow for August in comparison to nearby streams. Consequently, the Usquepaug–Queen River may require higher streamflow requirements than nearby rivers to protect the habitat provided by its higher baseflows.

Wetted-Perimeter Method

Streamflow requirements were determined by the Wetted-Perimeter method for seven riffle sites on the Usquepaug–Queen River (table 13). Wetted–Perimeter streamflow requirements, normalized for drainage area, ranged from 0.21 to 0.66 $ft^3/s/mi^2$. The median streamflow requirement was 0.41 $ft^3/s/mi^2$. Because channel alterations may change the streamflow requirements determined by the Wetted-Perimeter method, an alternative streamflow requirement for habitat protection can be determined by averaging only the Wetted-Perimeter results from unaltered sites. The Wetted-Perimeter streamflow requirements for the three most natural riffle sites were 0.41 $ft^3/s/mi^2$ for the Usquepaug River at Laurel Lanes, 0.50 $ft^3/s/mi^2$ for Fisherville Brook near Liberty Church Road, and 0.33 $ft^3/s/mi^2$ for Fisherville Brook near Pardon Joslin Road. The median of the Wetted-Perimeter streamflow requirements for these three sites is also 0.41 $ft^3/s/mi^2$.

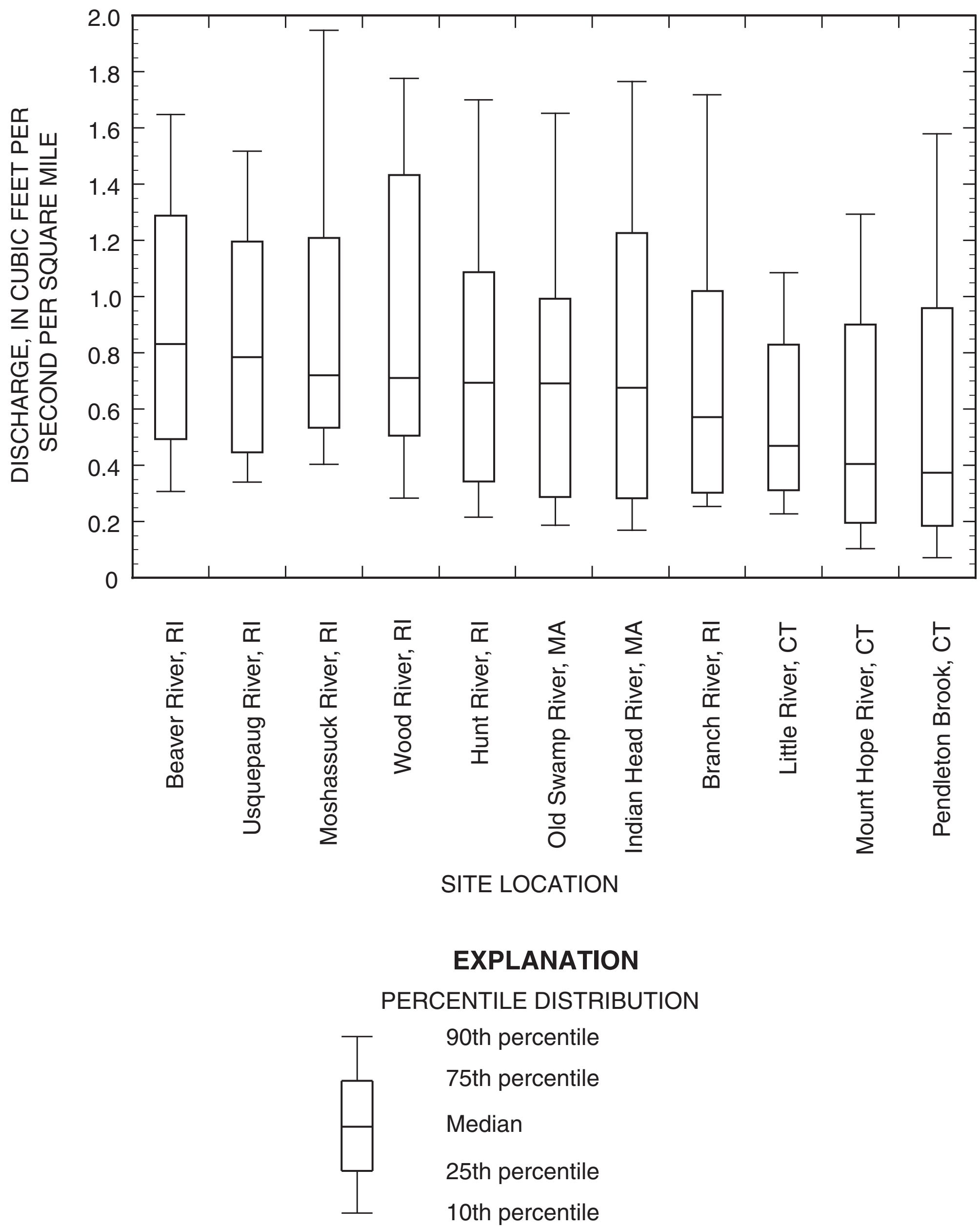

Figure 21. Distribution of monthly mean flow for August for 11 gaging stations in southern New England.

Streamflow requirements determined by the Wetted-Perimeter method often correspond to a water level that has just begun to rise up the stream banks (a fully-wetted channel bed). To reduce the subjectivity that may occur in those cases where the point of maximum curvature in the wetted-perimeter-to-discharge relation was difficult to determine, streamflow requirements were determined from breaks in the slope of the wetted-perimeter-discharge curves that corresponded to the point where the water level reaches the bottom of the stream bank, as determined from toe-of-bank elevations identified during site surveys. Because of the channel shape at some of the study sites, streamflow requirements identified by the Wetted-Perimeter method may provide only a minimal amount of habitat in some of the riffles. Those sites that have flat-bottomed, rectangular or trapezoidal channel shapes, such as the Usquepaug River at Route 138, Queen River at Dawley Road, and Queen River near William Reynolds Road, often have a fully-wetted

channel bed at very low discharges. Flows estimated by the Wetted-Perimeter method for these riffles may not necessarily provide water depths at the stream margins or within portions of the riffle that are sufficient for these areas to provide good habitat conditions for fish.

R2Cross Method

Streamflow requirements were determined by the R2Cross method for seven riffle sites on the Usquepaug–Queen River (table 13). R2Cross streamflow requirements, normalized for drainage area, ranged from 0.28 to 1.86 $ft^3/s/mi^2$ (table 13). The median streamflow requirement was 0.72 $ft^3/s/mi^2$.

Alterations to channel width can affect the streamflow requirements determined by the R2Cross method. Streamflow requirements may be higher in channels that have been widened, and lower in channels that are narrower than the natural channel. Because of the scarcity of suitable, unaltered riffle sites on the Usquepaug–Queen River, some of the study sites were altered sites. Efforts were made to locate cross sections at the least altered locations within these riffles. The study sites at the Usquepaug River near Route 138, Queen River near William Reynolds Road, and Locke Brook near Mail Road sites appear to have altered channels that may have affected the results of the R2Cross analysis. The study site near Route 138 has riprap on the right bank and may have a straightened channel because of the historic operation of mills at the site. Consequently, the stream channel at this site may be not be able to fully adjust its width naturally. The riffles at the Queen River near William Reynolds Road, and Locke Brook near Mail Road sites are immediately downstream of road crossings. The channels at these sites may have been widened relative to their unaltered channel width, and likely contain deposits of coarse-grained substrate that were eroded from scour holes downstream of the bridges during high flow. R2Cross streamflow requirements calculated for these sites may be higher than streamflow requirements calculated for unaltered channels.

Table 13. Streamflow requirements computed by Wetted-Perimeter and R2Cross methods for seven riffle study sites, Usquepaug–Queen River, Rhode Island

[USGS, U.S. Geological Survey; $ft^3/s/mi^2$, cubic feet per second per square mile]

USGS habitat site identifier	River and reach	Streamflow requirement	
		Wetted perimeter ($ft^3/s/mi^2$)	R2Cross ($ft^3/s/mi^2$)
U2	Usquepaug River near Laurel Lane	0.41	0.28
U1	Usquepaug River at Route 138	.25	.59
Q5	Queen River near Dawley Road	.21	1.82
Q3	Queen River near William Reynolds Road	.64	1.86
F2	Fisherville Brook at Liberty Church Road	.50	.72
F1	Fisherville Brook near Pardon Joslin Road	.33	.58
L1	Locke Brook at Mail Road	.66	1.31
	Mean	.43	1.02
	Median	.41	.72

Because channel alterations may change the streamflow requirements determined by the R2Cross method, an alternative streamflow requirement for habitat protection can be determined by averaging only the R2Cross results from unaltered sites. The R2Cross streamflow requirements for the three most natural riffle sites were 0.28 $ft^3/s/mi^2$ for the Usquepaug River at Laurel Lanes, 0.72 $ft^3/s/mi^2$ for Fisherville Brook near Liberty Church Road, and 0.58 $ft^3/s/mi^2$ for Fisherville Brook near Pardon Joslin Road. The median of the R2Cross streamflow requirements for these three sites is 0.58 $ft^3/s/mi^2$.

Other sites that may not meet the criteria for application of the R2Cross method include riffles that have marginal water-surface slopes for application of Manning's equation and riffles that are submerged at low to moderate flows by backwater from downstream controls. The high R2Cross streamflow requirements at the Queen River near Dawley Road may be attributed to the fact that the gradient of the riffle is near or below the recommended limits for application of Manning's equation. The riffle becomes a run at low to moderate flows and requires a high discharge to meet the R2Cross 1 ft/s mean-velocity criterion. Backwater conditions created by vegetation in the channel may also have affected the water levels in the riffle that were used for calibration of the flow model for this site. The study sites on the Usquepaug River near Laurel Lane and Fisherville Brook near Pardon Joslin Road also may become affected by backwater conditions at moderate to high flows, however; these sites appear to have sufficient gradient to remain riffles at the low flows identified as streamflow requirements.

COMPARISON OF STREAMFLOW REQUIREMENTS AND METHODS

Streamflow requirements for habitat protection were computed by the Tennant, ABF, and RVA methods on the basis of flow records from the Usquepaug River near Usquepaug stream gaging station (01117420) for the period 1976–2000. Flows at this gaging station are affected by upstream water withdrawals. Streamflow requirements determined from these records would likely be lower than those determined from natural streamflows or simulated streamflows without withdrawals. These preliminary values are useful, however, to indicate the magnitude of streamflow requirements. Once natural streamflows are simulated by the USGS using an HSPF model (G.C. Bent, U.S. Geological Survey, written commun., 2002), the Tennant, ABF, and RVA streamflow requirements can be recalculated for the Usquepaug gaging station and also can be computed for other locations in the basin such as the riffle sites where the Wetted-Perimeter and R2Cross methods were applied.

The streamflow requirements determined by the Tennant method for the 40-percent and 30-percent Q_{MA}, (considered by Tennant to provide good and fair summer-habitat conditions) were 0.85 and 0.64 $ft^3/s/mi^2$, respectively. The 0.79 $ft^3/s/mi^2$ streamflow requirement calculated on the basis of the ABF median of monthly mean flows is between the 0.40 and 0.30 Q_{MA} Tennant streamflow requirements, and thus identifies fair to good habitat conditions, according to Tennant (1976).

One advantage of the Tennant method is that it is is less sensitive to regulation than other methods, because its value is a percentage of a mean annual flow statistic that is heavily weighted to high flows that are least affected by summer withdrawals. In contrast, the ABF method based on the median of monthly mean flows for August is sensitive to regulation, because the streamflow depletion caused by summer water withdrawals is a large percentage of August streamflow. Despite summer water withdrawals, the median of monthly mean flow for August for the Usquepaug gaging station was higher than that determined from nine nearby gaging stations with virtually unaltered flow (fig. 21). This indicates that high summer streamflow requirements may be needed in the Usquepaug–Queen River to maintain summer low flows within the ranges of those that would have occurred naturally.

The R2Cross and Wetted-Perimeter methods require collection of site-specific physical and hydraulic data, such as channel geometry, average velocity, and mean depth at riffle sites. An advantage of the R2Cross and Wetted-Perimeter methods is that they are based on field observations and do not require data from a streamflow-gaging station, so the flow values obtained by these methods can be applied in hydrologically disturbed drainage basins and at either gaged or ungaged sites. During the site-selection process, however, care must be taken to select appropriate sites. Well defined riffle habitats that extend across the entire channel and that maintain hydraulic control over a range of low to moderate flows can be difficult to locate, and may be difficult to identify at some streamflows. Furthermore, differences in channel geometry among riffles can create variability in resulting streamflow requirements. In particular, alterations to channels can have a direct effect on the streamflow recommendations produced by these methods. Variability in the streamflow requirements calculated by the Wetted-Perimeter and R2Cross methods does not necessarily indicate inaccuracies in these methods (Annear and Conder, 1984). The streamflow requirements determined by the Wetted-Perimeter and R2Cross methods may differ between natural and altered channels, depending on the degree and type of alteration to the channel. Consequently, streamflow requirements determined for natural riffle sites may not be sufficient to protect habitat at sites in a widened channel, and flow requirements estimated at sites with a narrowed channel may not provide sufficient flows for habitat protection in unaltered stream reaches. The Wetted-Perimeter and R2Cross methods, therefore, should not be applied indiscriminately.

Summer streamflow requirements for habitat protection were computed for seven riffle sites by means of the Wetted-Perimeter and R2Cross methods (table 13). The median Wetted-Perimeter and R2Cross streamflow requirements were 0.41 $ft^3/s/mi^2$ and 0.72 $ft^3/s/mi^2$, respectively. If only the unaltered sites are considered, the median Wetted-Perimeter and R2Cross streamflow requirements are 0.41 and 0.58 $ft^3/s/mi^2$, respectively. R2Cross streamflow requirements were higher than Wetted-Perimeter streamflow requirements for all but one of the sites. R2Cross streamflow requirements tend to be higher because the method, as applied in this report, requires depth, velocity, and wetted-perimeter criteria to be met,

whereas Wetted-Perimeter streamflow requirements require only that the streambed be wetted to the bottom of the bank.

The streamflow requirements determined by the Wetted-Perimeter and R2Cross methods are compared in figure 22 to the distribution of monthly mean flows for the summer months for four gaging stations on streams with mostly unaltered flow for the 1976–2000 period: these stations include the Beaver River (01117468), Branch River (01111500), and Wood River (01117800) gaging stations in Rhode Island, and the Indian Head River (01105730) in Massachusetts. The R2Cross and Wetted-Perimeter streamflow requirements fall within the range of flows recommended by the RVA for July, August, and September, and are below the recommended monthly flow range for portions of June and October. Comparison of median streamflow requirements

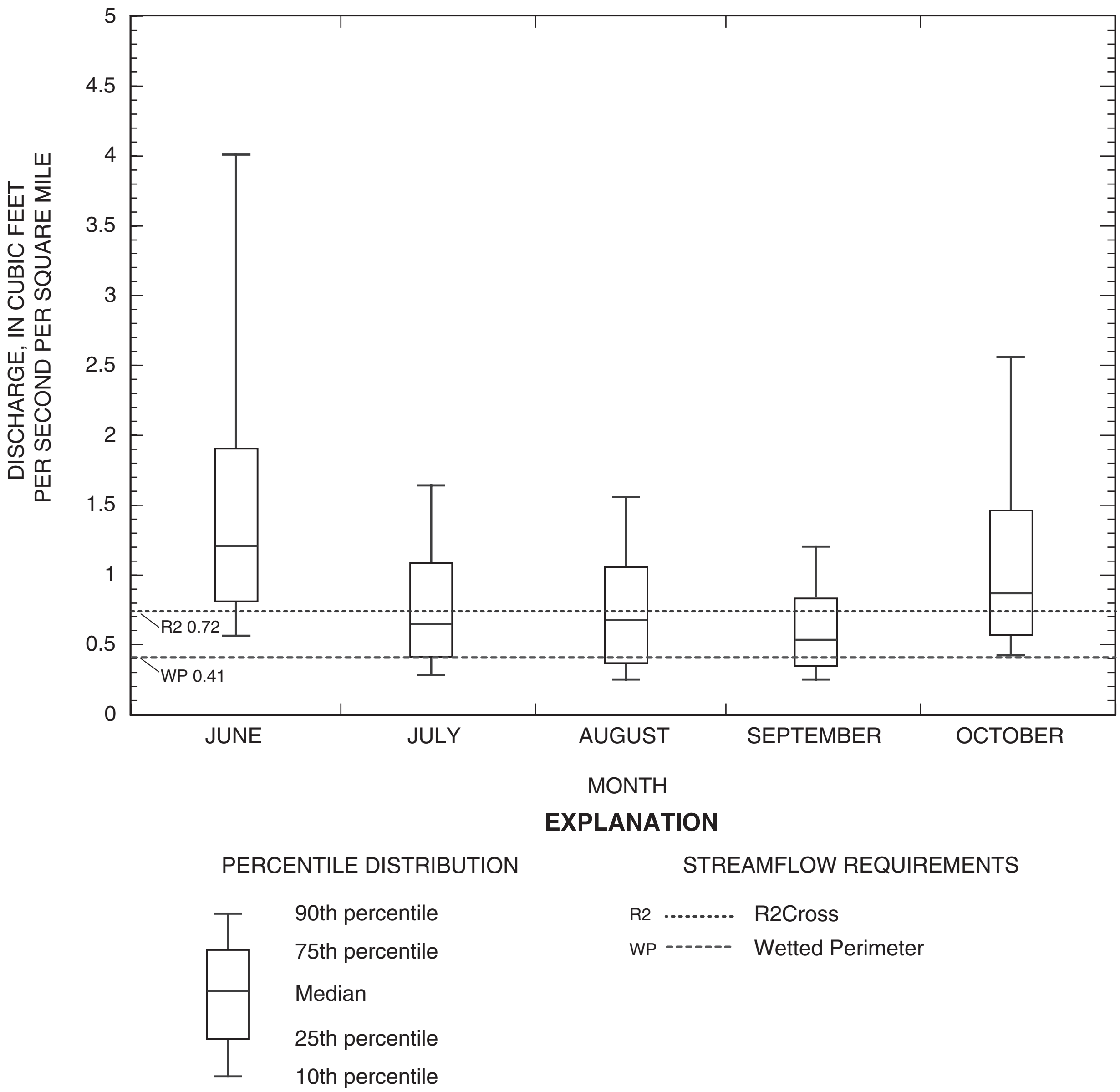

Figure 22. Distribution of median Wetted-Perimeter and R2Cross streamflow requirements for seven riffle sites on the Usquepaug–Queen River and the average distribution of the monthly mean flow during summer for the Beaver River (01117468), Branch River (01111500), and Wood River (01117800) gaging stations, Rhode Island, and the Indian Head River (01105730), Massachusetts.

determined by the Wetted-Perimeter and R2Cross methods to those determined by the Tennant method indicate that R2Cross streamflow requirements would provide habitat conditions that were fair to good and Wetted-Perimeter streamflow requirements would provide habitat conditions that were poor to fair when definitions for habitat quality identified by Tennant (1976) are used.

The streamflow requirements for habitat protection, determined from the median Wetted-Perimeter and R2Cross results from unaltered sites, were 0.41 and 0.58 $ft^3/s/mi^2$, respectively. The summer streamflow requirements determined for the Usquepaug–Queen River by applying the 30-percent Q_{MA} Tennant method and the ABF method based on the median of monthly mean flows for August to records from the Usquepaug gaging station (01117420), were 0.64 $ft^3/s/mi^2$ and 0.79 $ft^3/s/mi^2$, respectively. Averaging the results of these four methods results in a summer streamflow requirement for habitat protection, to one significant figure, of about 0.6 $ft^3/s/mi^2$ for the Usquepaug–Queen River. A streamflow requirement of about 0.6 $ft^3/s/mi^2$ is within the range of RVA flow-management targets for the months of July, August, and September, as determined for the Usquepaug gaging station and four nearby gaging stations with relatively unaltered flow. A streamflow of 0.6 $ft^3/s/mi^2$ will prevent the Usquepaug–Queen River from becoming segmented, and will provide habitat not only in the seven study riffles, but also throughout the basin. A summer streamflow requirement recalculated on the basis of natural flows simulated by the HSPF model, in combination with a varied flow regime identified by the RVA for the remainder of the year, will sustain fluvial fish communities and protect the stream integrity and natural ecosystem functions of unimpounded reaches of the Usquepaug–Queen River.

Standard-setting methods identify seasonal streamflow requirements that must sustain fish communities not only through the low-flow part of the summer (mid-July to mid-September), but also through the early (mid-June to mid-July) and late (mid-September to mid-October) parts of the summer and early fall when flows are generally higher. Although standard-setting streamflow requirements identify flows that provide habitat protection during the low-flow part of the summer, it is important to recognize that flows will naturally fall below these minimum streamflow requirements for some days during the low-flow period in late summer (fig. 22).

Because of the natural variability of streamflow, the period of time flows remain below streamflow requirements can vary from year to year. For example, records for the Usquepaug River gaging station (01117420) were screened to select years that had dry, normal, and wet summers (fig. 23). Dry, normal, and wet summers were defined on the basis of having 90-day minimum flows close to the 25th, 50th, and 75th percentiles for the 90-day minimum flow between 1976–2000, respectively. In a dry summer, flows could fall below a seasonal streamflow requirement of about 0.6 $ft^3/s/mi^2$ for several months, including much of July, August, and September (fig. 23*A*). In a normal summer, flows could fall below a seasonal streamflow requirement of about 0.6 $ft^3/s/mi^2$ for several weeks each month, including most periods of base flow during July, August, and September (fig. 23*B*). In a wet year, flows could fall below a seasonal streamflow requirement of about 0.6 $ft^3/s/mi^2$ for several weeks (fig. 23*C*), especially during periods of base flow during late summer.

A flow-duration curve was determined for the Usquepaug River near Usquepaug stream-gaging station (fig. 24). This curve is a cumulative frequency curve that shows the percentage of time during which specified discharges were equaled or exceeded for an average year for the period of record. It also shows the integrated effect of various factors that affect runoff, such as climate, topography, and geology (Zappia and Hayes, 1998). If the discharge on which the flow-duration curve is based represents the long-term flow conditions of a stream, the curve may be used to estimate the percentage of time specified discharges will be equaled or exceeded in the future (Searcy, 1959). For example, the daily mean flow of 76.8 ft^3/s is equaled or exceeded about 39 percent of the time and a discharge of 59.4 ft^3/s is exceeded about 50 percent of the time (fig. 3). A streamflow requirement of 21.7 (0.6 $ft^3/s/mi^2$) would be equaled or exceeded about 85 percent of the time. The 55 days during which flows may be below the streamflow requirement would not necessarily all occur in the summer, but could occur at any time during an average year.

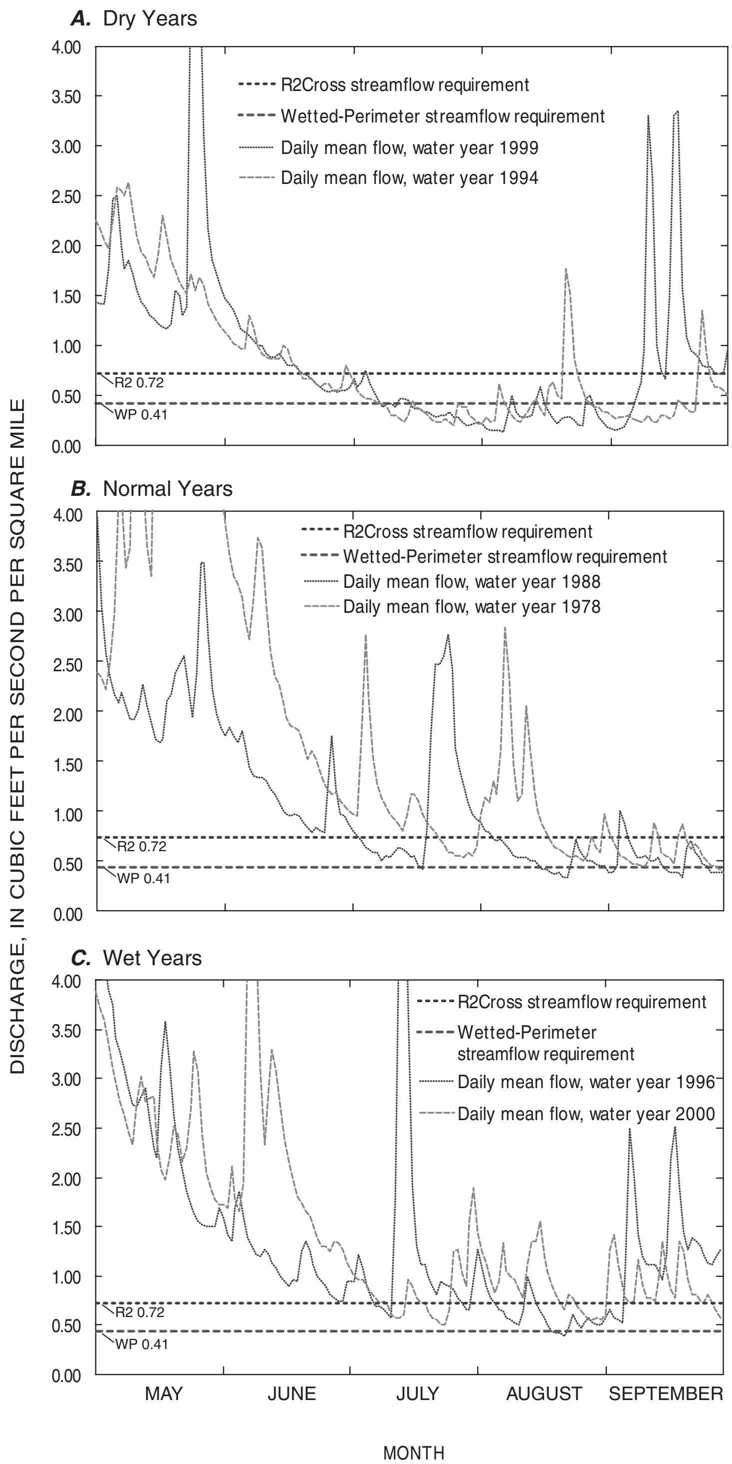

Figure 23. Median Wetted-Perimeter and R2Cross streamflow requirements, and daily mean streamflows at the Usquepaug River gaging station (01117420), Rhode Island, between May and September during dry, normal, and wet years: (*A*) dry years, 1994 and 1999, (*B*) normal years, 1978 and 1988, and (*C*) wet years, 1996 and 2000.

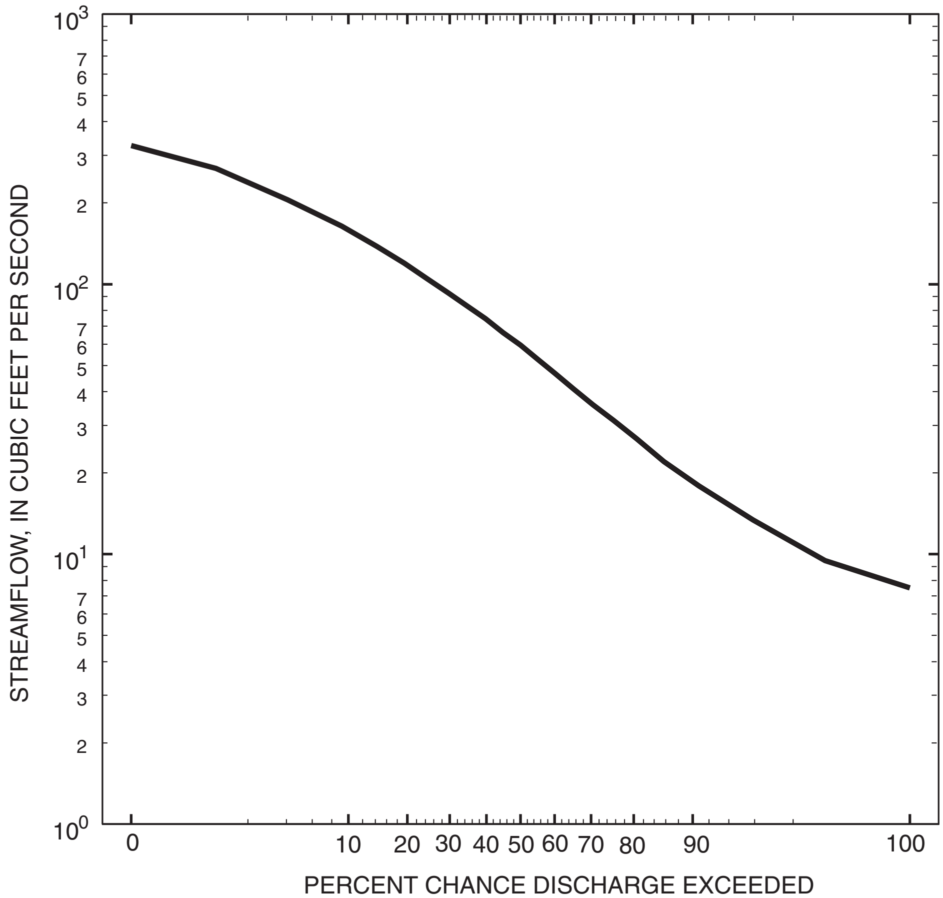

Figure 24. Flow-duration curve for the Usquepaug River near Usquepaug, Rhode Island, gaging station (01117420), 1958–2000.

SUGGESTIONS FOR FURTHER STUDY

A determination of an overall streamflow requirement for the Usquepaug–Queen River, as determined by the Wetted-Perimeter and R2Cross methods, would be more robust if a greater number of riffle sites were included in the analysis. The application of Wetted-Perimeter and R2Cross methods, however, is limited by the availability of unaltered riffle sites that have appropriate channel geometry for application of hydraulic models. Although there are additional riffles on tributaries that would be suitable for analysis, there are few additional riffle sites on the mainstem Usquepaug–Queen River where these methods could be applied. The inclusion of more tributary sites could bias the results of the overall analysis if streamflows, normalized for drainage area, differ between upstream and downstream reaches of the river. Although the current sample is too small to develop a definitive conclusion, the differences between the average of the Wetted-Perimeter and R2Cross streamflow requirements for the mainstem sites (0.59 $ft^3/s/mi^2$) and for the tributary sites (0.82 $ft^3/s/mi^2$) could indicate that higher streamflows, normalized for drainage area, may be needed to provide habitat protection in riffles in the headwater and tributary portions of the river.

The degree to which an altered flow regime departs from a natural flow regime and the resulting change in the structure and composition of a stream's aquatic community is poorly understood. More information is needed regarding the effects on aquatic communities when these streamflow requirements are met or not met. To assess the effects of changes in streamflow on aquatic communities, studies targeting the communities dependent upon flow and the habitats likely to be affected by flow changes are needed. In a

study of the relation between fish assemblages and flow in different stream habitats, Aadland (1993) concluded that riffle, raceway, and shallow-pool habitats were the most sensitive to flow fluctuations. Investigations of streamflow and habitat in the Usquepaug–Queen River demonstrated that riffles are the first channel type to lose substantial habitat as discharge decreases; therefore, assessments of fish and macroinvertebrate communities in riffles and nearby habitats would serve as a useful indicator of the effects of flow alterations on stream health. Application of a riffle-based approach for determining streamflow requirements in Rhode Island requires more information about: (1) the natural seasonal variability of hydraulic conditions in riffles, (2) how those variations relate to conditions in nearby habitats, and (3) how fish and macroinvertebrate assemblages use those habitats. Long-term monitoring of fish populations in rivers where streamflow requirements have been established would improve the understanding of the relation between streamflow and the reproduction, recruitment, growth, and other seasonal life-history needs of stream fish (Tyrus, 1990).

Methods for setting a minimum streamflow for habitat protection assume that summer low flow and habitat availability are limiting criteria for aquatic life. The methods compared in this report do not account for other flow-related factors that affect the quality of stream habitat such as water quality, temperature, or impoundment; nor do the methods directly quantify biological trade-offs for different flows or seasons. Other methods, such as the Instream Flow Incremental Methodology (IFIM) (Bovee and others, 1997), which was not used in this study, could be applied to account for factors other than flow as a limit on aquatic life, or to compare the effects of incremental differences in flow created by numerous alternative water uses upon specific species or life stages of fish or aquatic invertebrates.

SUMMARY AND CONCLUSIONS

Stream habitat, fish communities, and hydrologic conditions were investigated in the Usquepaug–Queen River Basin in southern Rhode Island. Habitats were assessed at 13 sites on the mainstem and tributaries from July 1999 to September 2000. Study sites were revisited by volunteer teams and by USGS personnel to document habitat conditions at different flows. Channel types are predominantly low-gradient glides, pools, and runs that have a sand and gravel streambed and a forest or shrub riparian zone. Fish habitat is provided mostly by features along the stream margins such as overhanging brush, undercut banks supported by roots, and woody debris. These habitat features decrease in quality and availability with declining streamflows and generally become unavailable once streamflows drop to the point at which water recedes from the stream banks. In low-gradient reaches, submerged aquatic vegetation can provide instream habitat once water recedes from the stream banks. The quality of that habitat decreases, however, as water depths and velocity decrease with declining streamflows. Riffles were identified as critical habitat areas because they are among the first to exhibit habitat losses during low-flow periods.

Stream-temperature data were collected at eight sites during summer 2000 to indicate the suitability of those reaches for cold-water fish communities. Stream temperatures provide cold-water habitat in the Fisherville Brook and Locke Brook tributaries and in the mainstem of the Queen River downstream of the confluence with Fisherville Brook. Warm stream temperatures and impoundments may make marginal habitat for cold-water species in the headwaters of the Queen River and in the Usquepaug River downstream from Glen Rock Reservoir. Consequently, cold-water fish communities that may exist in these reaches would appear to have little tolerance for additional temperature changes that could possibly be created by increased water withdrawals.

Recent fish collections were analyzed to determine fish-community composition. Fish-community composition was determined for 12 sites from tributaries and the Queen River headwaters, sampled in 1998, and three sites on the mainstem Usquepaug–Queen River sampled in 2000. Classification of the fish into habitat-use groups and comparison of fish in the mainstem Usquepaug–Queen River to target fish communities developed for nearby streams in New England indicated that the sampled reaches of the mainstem Usquepaug–Queen River contained riverine fish species in proportions that are near the ranges that could be expected.

Streamflow data from the gaging station Usquepaug River near Usquepaug were used to determine streamflow requirements by use of the Tennant method and New England Aquatic-Base-Flow

method based on the median of monthly mean flows for August, and to define a flow regime that mimics the river's natural flow regime by use of the Range of Variability Approach (RVA). Flows at the Usquepaug River gaging station are reduced by water withdrawals upstream, and preliminary results are presented to indicate lower limits for the flow requirements determined by those methods. Streamflow requirements for habitat protection for the Usquepaug River gaging station were 0.64 $ft^3/s/mi^2$ for the Tennant method based on 30-percent of the Mean Annual Flow (Q_{MA}), and 0.79 $ft^3/s/mi^2$ for the New England Aquatic-Base-Flow method based on the median of monthly mean flows for August. Despite summer water withdrawals, the median of monthly mean flows for August at the Usquepaug gaging station was higher than that for nine nearby gaging stations that have virtually unaltered flow. These high base flows indicate that high summer streamflow requirements may be needed in the Usquepaug–Queen River to maintain summer low flows within the ranges of naturally occurring low flows.

Streamflow requirements for habitat protection were determined at seven riffle sites, two on the mainstem Usquepaug River, one on the mainstem Queen River, and four on tributaries and the Queen River headwaters. The median streamflow requirements for habitat protection for the mainstem and tributary sites, were 0.41 $ft^3/s/mi^2$ determined by the Wetted-Perimeter method, and 0.72 $ft^3/s/mi^2$ determined by the R2Cross method. R2Cross streamflow requirements were higher than Wetted-Perimeter streamflow requirements for most sites. Comparison of median streamflow requirements determined by the Wetted-Perimeter and R2Cross methods to those determined by the Tennant method indicate that R2Cross streamflow requirements would provide habitat conditions that were fair to good and Wetted-Perimeter streamflow requirements would provide habitat conditions that were poor to fair when definitions for habitat quality identified by Tennant are used.

The R2Cross and Wetted-Perimeter streamflow requirements bracket the lower quartiles of monthly mean streamflow for July and August at the Usquepaug gage, and include much of the interquartile range of flows for September. Streamflows recommended by these methods, therefore, fall within the range of flows recommended by the RVA for the months of July, August, and September, and are below the RVA recommended monthly flows for portions of June and October.

The streamflow requirement for habitat protection, determined from results of the median Wetted-Perimeter and R2Cross analyses for unaltered sites, were 0.41 and 0.58 $ft^3/s/mi^2$, respectively. The summer streamflow requirements for the Usquepaug–Queen River determined by applying the 30-percent Q_{MA} Tennant method and the ABF method based on the median of monthly mean flows for August to the Usquepaug River gaging station records were 0.64 $ft^3/s/mi^2$ and 0.79 $ft^3/s/mi^2$, respectively. Averaging the results of these four methods results in a summer streamflow requirement for habitat protection for the Usquepaug–Queen River, to one significant figure, of about 0.6 $ft^3/s/mi^2$. A streamflow requirement of about 0.6 $ft^3/s/mi^2$ is within the range of the RVA flow-management targets for the months of July, August, and September, as determined from nearby gaging stations with mostly unaltered flow. A flow-duration curve for the Usquepaug gage (01117420) shows that under current conditions, streamflows would be below this flow for 15 percent of the time in an average year. A streamflow of 0.6 $ft^3/s/mi^2$ will prevent the Usquepaug–Queen River from becoming segmented, and will provide habitat not only in the seven study riffles, but also throughout the basin. A summer streamflow requirement recalculated on the basis of natural flows simulated by the USGS using an HSPF model, in combination with a varied flow regime identified by the RVA for the remainder of the year, will provide habitat to sustain fluvial fish communities and protect the stream integrity and natural ecosystem functions of unimpounded reaches of the Usquepaug–Queen River.

REFERENCES CITED

Aadland, L.P., 1993, Stream habitat types—their fish assemblages and relationship to flow: North American Journal of Fisheries Management, v. 13, p 790–806.

Annear, T.C., and Conder, A.L., 1984, Relative bias of several fisheries instream flow methods: North American Journal of Fisheries Management, v. 4, p. 531–539.

Armour, C.L., 1991, Guidance for evaluating and recommending temperature regimes to protect fish: U.S. Fish and Wildlife Service, Biological Report 90 (22) 13, p.

Armstrong, D.S., Richards, T.A., and Parker, G.W., 2001, Assessment of habitat, fish communities, and streamflow requirements for habitat protection, Ipswich River, Massachusetts, 1998–1999: U.S. Geological Survey Water-Resources Investigations Report 01-4161, 72 p., 1 CD-ROM.

Baevsky, Y.H., 1991, Physical and water-quality characteristics affecting trout-spawning habitat in the Quashnet River, Cape Cod, Massachusetts: U.S. Geological Survey Water-Resources Investigations Report 91-4045, 21 p.

Bain, M.B., and Knight, J.G., 1996, Classifying stream habitat using fish community analyses, *in* Leclerc, Michel, Capra, Herve, Valentin, Sylvie, Boudreault, Andre, and Cote, Yvon, eds., Proceedings of the second IAHR Symposium on habitat hydraulics: Quebec, Canada, June Ecohydraulics 2000, Institut National de la Recherche Scientifique-Eau, Ste-Foy, p. B107–B117.

Bain, M.B., and Mexler, M.S., 2000, Defining a target fish community for planning and evaluating enhancement of the Quinebaug River in Massachusetts and Connecticut: Ithaca, NY, New York Cooperative Fish and Wildlife Research Unit, Cornell University, 20 p.

Bain, M.B., and Stevenson, N.J., eds., 1999, Aquatic habitat assessment—Common methods: Bethesda, MD, American Fisheries Society, 216 p.

Bain, M.B., and Travnichek, V.T., 1996, Assessing impacts and predicting restoration benefits of flow alteration in rivers developed for hydroelectric power production, *in* Leclerc, Michel, Capra, Herve, Valentin, Sylvie, Boudreault, Andre, and Cote, Yvon, eds., Proceedings of the second IAHR Symposium on habitat hydraulics: Quebec, Canada., June Ecohydraulics 2000, Institut National de la Recherche Scientifique-Eau, Ste-Foy, B543–B552.

Barbour, M.T., Gerritsen, J., Snyder, B.D., and Stribling, J.B., 1999, Rapid bioassessment protocols for use in streams and wadeable rivers—periphyton, benthic macroinvertebrates, and fish, second edition: Washington, D.C., U.S. Environmental Protection Agency, Office of Water, EPA 841-B-99- 002, variously paged.

Barnes, H.H., 1967, Roughness characteristics of natural channels: U.S. Geological Survey Water-Supply Paper 1849, 213 p.

Bovee, K.D., Lamb, B.L., Bartholow, J.M., Stalnaker, C.B., Taylor, Jonathon, and Henriksen, Jim, 1998, Stream habitat analysis using the Instream Flow Incremental Methodology: U.S. Geological Survey Biological Resources Division Information and Technology Report 1998–0004, 131 p.

Brunner, G.W., 2001, HEC-RAS, River Analysis System User's Manual, Version 3.0, January 2001: Davis, CA, U.S. Army Corps of Engineers Hydrologic Engineering Center (HEC), CDP-68, variously paged.

Cervione, M.A., Jr., Richardson, A.R., and Weiss, L.A., 1993, Low-flow characteristics of selected streams in Rhode Island: U.S. Geological Survey Water-Resources Investigation Report 93-4046, 16 p.

Charles Ritzi and Associates, 1987, Computation of USFWS aquatic base flow (ABF) for regulated streams: Winthrop, ME, Charles Ritzi and Associates, 16 p.

Colorado Water Conservation Board, 2001, Memorandum to Colorado Water Conservation Board Members, May 11, 2001, accessed on November 30, 2001, at URL http://cwcb.state.co.us/agendas/May%2001/14%20-ISF%20Quantification%20Policy.pdf.

Denny, C.S., 1982, Geomorphology of New England: U.S. Geological Survey Professional Paper 1208, 18 p.

Dickerman. D.C., Kliever, J.D., and Stone, J.R., 1997, Hydrogeology, water quality, and simulation of ground-water development alternatives in the Usquepaug–Queen ground-water reservoir, southern Rhode Island: U.S. Geological Survey Water-Resources Investigations Report 97-4126, 48 p.

Dunbar, M.J., Acreman, M.C., Gustard, A., Elliott, C.R.N., 1998, Overseas approaches to setting river flow objectives: Phase I report to the Environmental Agency, Environmental Agency R&D Technical report W6-161.

Elliott, J.M., 1994, Quantitative ecology and the Brown Trout: New York, Oxford University Press, 286 p.

Espegren, G.D., 1996, Development of instream flow recommendations in Colorado using R2CROSS: Denver, CO, Water Conservation Board, 34 p.

_____1998, Evaluation of the standards and methods used for quantifying instream flows in Colorado: Denver, CO, Water Conservation Board, 18 p.

Flebbe, P.A., 1997, Global climate change and fragmentation of native brook trout distribution in the southern Appalachian Mountains, *in* Gresswell, R. E., Dwyer, P., and Hamre, R.H., eds. Proceedings of Wild Trout VI—Putting the native back in wild trout: Bozeman, MT, August 17–20, 1997, Montana State University, p. 117–121.

Galat, D.L., and Lipkin, Robert, 1999, Characterizing the natural flow regime of the Missouri River using historical variability in hydrology, accessed July 3, 2002, at URL http://infolink.cr.usgs.gov/Science/Hydro/flowregime.html

Guthrie, R.C., Stolgitis, J.A., and Bridges, W.L., 1973, Pawcatuck River Watershed Fisheries Management Survey: Rhode Island Division of Fisheries and Wildlife, Fisheries Report No. 1, 61 p.

Hicks, D.M., and Mason, P.D., 1991, Roughness characteristics of New Zealand Rivers: Wellington, New Zealand, Water Resources Survey, DSIR Marine and Freshwater, 329 p.

Hill, M.T., Platts, W.S., and Beschta, R.L., 1991, Ecological and geomorphological concepts for instream and out-of-channel flow requirements: Rivers, v. 2, no. 3, p. 198–210.

Instream Flow Council, 2002, Instream flows for riverine resource stewardship: Instream Flow Council, 411 p.

Ipswich River Fisheries Restoration Task Group, 2002, Ipswich River Fisheries current status and restoration approach, accessed December 30, 2002, at URL http://www.ipswichriver.org/FishRestReport.pdf and http://www.ipswichriver.org/FishRestReportA.pdf, 21 p.

Johnston, H.E., 1986, Rhode Island surface water resources, *in* Moody, D.W., and others, eds., National Water Summary 1985—Hydrologic events and surface-water resources: U.S. Geological Survey Water-Supply Paper 2300, p. 407–412.

Kliever, J.D., 1995, Hydrologic data for the Usquepaug–Queen River Basin, Rhode Island: U.S. Geological Survey Open-File Report 95-305, 68 p.

Kulik, B.H., 1990, A method to refine the New England aquatic base flow policy: Rivers, v. 1, no. 1, p. 8–22.

Lang, Vernon, 1999, Questions and answers on the New England flow policy: Concord, NH, U.S. Fish and Wildlife Service, 9 p.

Lapham, W.W., 1989, Use of temperature profiles beneath streams to determine rates of vertical ground-water flow and vertical hydraulic conductivity: U.S. Geological Survey Water-Supply Paper 2337, 35 p.

Leathe, S.A., and Nelson, F.A., 1986, A literature evaluation of Montana's wetted perimeter inflection point method for deriving instream flow recommendations: Helena, MT, Department of Fish, Wildlife, and Parks, 70 p.

Lohr, S.C., 1993, Wetted stream channel, fish-food organisms and trout relative to the wetted perimeter inflection method: Bozeman, MT, Montana State University, Ph.D. dissertation, 246 p.

MacBroom J.R., 1998, The river book—The nature and management of streams in glaciated terranes: Hartford, CT, Connecticut Department of Environmental Protection, 242 p.

Nehring, R.B., 1979, Evaluation of instream flow methods and determination of water quantity needs for streams in the State of Colorado: Fort Collins, CO, Division of Wildlife, 144 p.

Nelsen, F.A., 1984, Guidelines for using the wetted perimeter (WETP) computer program of the Montana Department of Fish, Wildlife, and Parks: Bozeman, MT, Montana Department of Fish, Wildlife, and Parks, variously paged.

Pawcatuck Watershed Partnership, 2001, Pawcatuck Watershed Report: U.S. Environmental Protection Agency, Region 1, 20 p.

Picard, C.R., 1995, Factors that predict brook trout distribution, thermal habitat, and abundance in northwestern Ontario streams: Canada, Lakehead University, Masters thesis, 282 p.

Poff, N.L., Allen, J.D., Bain, M.B., Karr, J.R., Prestagaard, K.L., Richter, B.D., Sparks, R.E., and Stromberg, J.C., 1998, The natural flow regime—a paradigm for river conservation and restoration: Bioscience, v. 47, p. 769–784.

Richter, B.D., Baumgartner, J.V., Powell, Jennifer, and Braun, D.P., 1996, A method for assessing hydrologic alteration within ecosystems: Conservation Biology, v. 10, p. 1163–1174.

Richter, B.D., Baumgartner, J.V., Wigington, Robert, and Braun, D.P., 1997, How much water does a river need?: Freshwater Biology, v. 37, p. 231–249.

Ries, K.G., III, 1997, August median streamflows in Massachusetts: U.S. Geological Survey Water-Resources Investigation Report 97-4190, 27 p.

Searcy, J.K., 1959, Flow-duration curves: U.S. Geological Survey Water-Supply Paper 1542-A, 33 p.

Socolow, R.S., Comeau, L.Y., Zanca, J.L., and Ramsbey, L.R., 1999, Water resources data, Massachusetts and Rhode Island, water year 1998: U.S. Geological Survey Water-Data Report, USGS-WDR-MA-RI-98-1, 438 p.

Socolow, R.S., Whitley, J.S., Murino, Domenic, Jr., and Ramsbey, L.R., 2001, Water resources data, Massachusetts and Rhode Island, Water year 2000: U.S. Geological Survey Water-Data Report, USGS-WDR-MA-RI-00-1, 459 p.

Socolow, R.S., Zanca, J.L., Murino, Domenic, Jr., and Ramsbey, L.R., 2000, Water resources data, Massachusetts and Rhode Island, water year 1999: U.S. Geological Survey Water-Data Report, USGS-WDR-MA-RI-99-1, 401 p.

Stark, J.R., Armstrong, D.S., and Zwilling, D.R., 1994, Stream-aquifer interactions in the Straight River Area, Becker and Hubbard Counties, Minnesota: U.S. Geological Survey Water-Resources Investigations Report 94-4009, 83 p.

Sullivan, Kathleen, Martin, D.J., Cardwell, R.D., Toll, J.E., and Drake, Steven, 2000, An analysis of the effects of temperature on salmonids of the Pacific Northwest with implications for selecting temperature criteria: Portland, OR, Sustainable Ecosystems Institute, 192 p., accessed August 21, 2002 at URL http://www.sei.org/downloads/reports/salmon2000.pdf.

Tennant, D.L., 1976, Instream flow regimens for fish, wildlife, recreation, and related environmental resources, *in* Instream flow needs, Volume II: Boise, ID, Proceedings of the symposium and specialty conference on instream flow needs, May 3–6, American Fisheries Society, p. 359–373.

The Nature Conservancy, 2002, Queen's River Preserve, accessed July 3, 2002, at URL http://nature.org/wherewework/northamerica/states/rhodeisland/preserves/art5350.html.

Tyrus, H.M., 1990, Effects of altered stream flows on fishery resources: Fisheries, v. 15, no. 3, p. 18–20.

U.S. Department of Agriculture, 1998, WinXSPRO, A channel cross-section analyzer, Users Manual: Fort Collins, CO, U.S. Department of Agriculture, Forest Service, Rocky Mountain Experiment Station, 97 p.

U.S. Fish and Wildlife Service, 1981, Interim regional policy for New England stream flow recommendations: Newton Corner, MA, U.S. Fish and Wildlife Service, 3 p.

Zappia, Humbert, and Hayes, D.C., 1998, A demonstration of the instream flow incremental methodology, Shenandoah River, Virginia: U.S. Geological Survey Water-Resources Investigations Report 98-4157, 30 p.

APPENDIX 1
Study-Site Descriptions and Documentation of Input and Calibration Data for HEC-RAS and WinXSPro Models

APPENDIX 1
STUDY-SITE DESCRIPTIONS AND DOCUMENTATION OF INPUT AND CALIBRATION DATA FOR HEC-RAS AND WINXSPRO MODELS

The Appendix includes study-site descriptions and documentation for WINXSPro and HEC-RAS models used to simulate hydraulic parameters for determination of Wetted-Perimeter and R2Cross streamflow requirements for:

1. Site U2, Usquepaug River near Laurel Lane
2. Site U1, Usquepaug River at Route 138
3. Site Q5, Queen River near Dawley Road
4. Site Q3, Queen River near William Reynolds Road
5. Site L1, Locke Brook at Mail Road
6. Site F2, Fisherville Brook at Liberty Church Road
7. Site F1, Fisherville Brook near Pardon Joslin Road

The values in the appendix tables are the output data from the models. For some instances, there may be small differences between the values in these tables and those appearing in the text. For example, the slopes reported in the text are the values input into the model. These values may differ slightly from the slopes in the appendix tables because HEC-RAS adjusts the slope at higher discharges. Values reported in the appendix for the hydraulic parameters used to determine R2Cross streamflow requirements (wetted perimeter, mean depth, mean velocity) are from the staging tables output by the models. The staging tables were created for small incremental differences in discharge. For some cases, the hydraulic parameters that met the R2Cross criteria fell between successive discharges in the staging tables. For these cases, the discharge meeting the criteria and reported in the text was extrapolated between successive values in the staging table. Values in the appendix tables, however, are those for the discharge in the staging table where the criteria are first met. In all cases differences are very minor.

1. Site U2, Usquepaug River near Laurel Lane, Richmond/South Kingstown, Rhode Island

One cross section was surveyed in this reach. The cross section was located at the upstream end of the riffle. This section is a hydraulic control and creates a glide habitat that extends upstream for a considerable distance. The riffle cross section is predominantly trapezoidal in shape, with a low bank and flood plain on the left side of the channel. The flood plain on the right bank is absent, because the river at that location is adjacent to a steep bank along the right side of the stream valley.

The stream slope in the riffle was surveyed to be 0.004 ft/ft, at a low-flow discharge of 25.8 ft^3/s. Manning's equation was used to calculate a roughness at this discharge of 0.040. Bankfull elevations were determined in the field during surveying and the channel roughness at bankfull flow was estimated by means of Barnes (1967) and Hicks and Mason (1991) to be 0.025. Manning's equation was applied with WinXSPro version 2.0 software (U.S. Department of Agriculture, 1998) and calibrated to the measured conditions, to develop stage-discharge relations at the sites. A bankfull flow of 122 ft^3/s was estimated by determining the discharge corresponding to a bankfull stage identified in the field. Bankfull channel width and bankful wetted perimeter at the cross section were determined to be 28.28 and 28.98 ft, respectively. Hydraulic parameters simulated by WinXSPRO and used to determine R2Cross and Wetted Perimeter streamflow requirements are shown in table 1.1.

The R2Cross criteria for determining streamflow requirements were an average depth of 0.28 ft, a wetted perimeter of 14.49 ft, and an average velocity of 1.0 ft/s. These criteria were determined from the model to be met at a discharge of 9.4 ft^3/s, or about 0.28 $ft^3/s/mi^2$. At this discharge the water depth in the deepest portion of the cross section was about 0.82, and the average depth in the section was 0.43 ft. The wetted perimeter was 22 ft, or about 76 percent of bankfull wetted perimeter. The R2Cross streamflow requirement was determined from the discharge corresponding to the mean-velocity criterion of 1.0 ft/s, the most limiting R2Cross criterion.

A wetted perimeter-discharge relation was determined for the cross section with WinXSPRO. Breaks in the wetted perimeter-discharge relation were used to identify a discharge of about 14 ft^3/s, or 0.41 $ft^3/s/mi^2$. At this discharge, the water depth in the deepest part of the cross section and the average depth of the section were simulated to be 0.94 and 0.5 ft, respectively. The wetted perimeter was estimated to be 24.9 ft, or about 86 percent of bankfull wetted perimeter. The mean velocity for the section was estimated to be 1.2 ft/s.

Table 1.1. Hydraulic criteria simulated by WinXSPRO for the Usquepaug River near Laurel Lane, Richmond/South Kingstown, Rhode Island

[Z, stage; A, area; P, wetted perimeter; W, width; R, hydraulic radius; D, average depth; S, slope; *n*, Manning's n; V, average velocity; Q, discharge; ft, foot; ft^3/s, cubic feet per second; ft^2, square feet]

Condition	Hydraulic parameters									
	Z (ft)	A (ft^2)	P (ft)	W (ft)	R (ft)	D (ft)	S (ft/ft)	n	V (ft/s)	Q (ft^3/s)
Meets R2Cross wetted-perimeter criterion	0.43	2.12	14.34	14.16	0.15	0.15	0.004	0.059	0.43	0.92
Meets R2Cross average-depth criterion	.60	4.94	18.16	17.95	.27	.28	.004	.055	.69	3.39
Field-identified bottom of bank	.72	7.26	21.05	20.81	.34	.35	.003	.052	.84	6.08
Meets R2Cross average-velocity criterion	.82	9.39	22.08	21.82	.43	.43	.003	.049	1.00	9.39
Wetted-Perimeter streamflow requirement	.94	12.22	24.94	24.66	.49	.50	.003	.046	1.15	14.08
Aquatic-Base-Flow 0.5 $ft^3/s/mi^2$ default flow	.96	12.71	25.12	24.83	.51	.52	.003	.046	1.19	15.09
Stage of calibration discharge (25.8 ft^3/s)	1.12	16.78	26.25	25.91	.64	.65	.003	.042	1.49	24.95
Stage of field-identified bankfull discharge	1.80	35.24	28.98	28.28	1.22	1.25	.003	.025	3.46	121.78

2. Site U1, Usquepaug River at Route 138, Richmond/South Kingstown, Rhode Island

Two cross sections were surveyed in this reach. Both cross sections are located within a riffle with moderate slope and do not serve as isolated hydraulic controls. The channel cross sections are roughly trapezoidal in shape, with a low flood plain on the left side and riprap on the right bank. Alterations to channel geometry, hardening of the streambed, riprap along the right bank, and an upstream dam could affect the streamflow requirements determined by the R2Cross and Wetted-Perimeter methods at this site.

At the upstream section, the water-surface slope was surveyed to be 0.006 ft/ft in the area of the riffle and 0.005 ft/ft for the reach. Manning's equation was used to calculate a roughness of about 0.075 for discharges between 20 and 30 ft^3/s. Bankfull elevations were determined in the field during surveying, and the roughness at bankfull flow was estimated by means of Barnes (1967) and Hicks and Mason (1991) to be 0.05. Manning's equation was applied using WinXSPro version 2.0 software (U.S. Department of Agriculture, 1998) and calibrated to the measured conditions to develop stage-discharge relations at the site. Bankfull flow at the site was estimated to be 116 ft^3/s. Bankfull channel width and bankfull wetted perimeter at the cross section were determined to be 32.98 and 34.52 ft, respectively. Hydraulic parameters simulated by WinXSPRO and used to determine R2Cross and Wetted-Perimeter streamflow requirements are shown in table 1.2.

The three R2Cross criteria for determining streamflow requirements were an average depth of 0.33 ft, a wetted perimeter of 17.26 ft, and an average velocity of 1.0 ft/s. These criteria were determined from the model to be met at a discharge of about 17.0 ft^3/s, or about 0.52 $ft^3/s/mi^2$. At this discharge, the water depth in the deepest portion of the cross section was about 0.88, and the average depth in the section was 0.59 ft. The wetted perimeter was 30.0 ft, or about 87 percent of bankfull wetted perimeter. The limiting R2Cross criterion was the discharge having a mean velocity of 1.0 ft/s.

A wetted perimeter-discharge relation was determined for the cross section with WinXSPRO. Because of the section's flat streambed, possibly created by channel alterations, low discharges of about 0.7 ft^3/s will wet the channel to the bottom of the bank identified in the field. Depths are extremely shallow at this low discharge value, however, and water levels are below the top of the cobbles and boulders in the streambed. Breaks in the wetted perimeter-discharge relation occur at a discharge of about 4.8 ft^3/s, or 0.15 $ft^3/s/mi^2$. At this discharge, the depth in the deepest part of the cross section and the average depth of the section were estimated to be 0.58 and 0.29 ft, respectively. The wetted perimeter was estimated to be 29.34 ft, or about 85 percent of bankfull wetted perimeter. The mean velocity for the section was estimated to be 0.57 ft/s.

Table 1.2. Hydraulic criteria simulated by WinXSPRO for the Usquepaug River at Route 138, upstream section, Richmond/South Kingstown, Rhode Island

[Z, stage; A, area; P, wetted perimeter; W, width; R, hydraulic radius; D, average depth; S, slope; *n*, Manning's n; V, average velocity; Q, discharge; ft, feet; ft^3/s, cubic feet per second; ft^2, square feet]

Condition	Hydraulic parameters									
	Z (ft)	A (ft^2)	P (ft)	W (ft)	R (ft)	D (ft)	S (ft/ft)	n	V (ft/s)	Q (ft^3/s)
Field-identified bottom of bank	0.25	2.03	13.05	12.90	0.16	0.16	0.006	0.095	0.35	0.71
Meets R2Cross wetted-perimeter criterion	.38	3.82	17.46	17.18	.22	.22	.006	.091	.46	1.74
Wetted-Perimeter streamflow requirement	.58	8.34	29.34	28.75	.28	.29	.006	.085	.57	4.78
Meets R2Cross average-depth criterion	.62	9.49	29.42	28.79	.32	.33	.006	.084	.63	5.99
Aquatic-Base-Flow 0.5 $ft^3/s/mi^2$ default flow	.84	15.85	29.90	28.97	.53	.55	.006	.078	.94	14.92
Meets R2Cross average-velocity criterion	.88	17.01	29.99	29.00	.57	.59	.006	.076	1.00	16.98
Stage of calibration discharge (20.6 ft^3/s)	.93	18.47	30.16	29.13	.61	.63	.006	.075	1.07	19.72
Stage of calibration discharge (32.9 ft^3/s)	1.15	24.96	31.02	29.87	.80	.84	.005	.069	1.38	34.56
Stage of field-identified bankfull discharge	1.80	45.26	34.52	32.98	1.31	1.37	.005	.050	2.55	115.51

At the downstream section, the water-surface slope was surveyed to be 0.007 ft/ft at a discharge of 20.6 ft^3/s, and 0.006 at a discharge of 32.9 ft^3/s. Manning's equation was used to calculate a roughness of about 0.08 at a discharge of 20.6 ft^3/s. Bankfull elevations were determined in the field during surveying, and the roughness at bankfull flow was estimated by means of Barnes (1967) and Hicks and Mason (1991) to be 0.05. Manning's equation was applied with WinXSPro version 2.0 software (U.S. Department of Agriculture, 1998) and calibrated to the measured conditions to develop stage-discharge relations at the site. Bankfull discharge at the site was estimated to be about 112 ft^3/s. Bankfull channel width and bankful wetted perimeter at the cross section were determined to be 39.14 and 41.49 ft, respectively. Hydraulic parameters simulated by WinXSPRO and used to determine R2Cross and Wetted-Perimeter streamflow requirements are shown in table 1.3.

The three R2Cross criteria for determining streamflow requirements were an average depth of 0.39 ft, a wetted perimeter of 20.74 ft, and an average velocity of 1.0 ft/s. These criteria were determined from the model to be met at a discharge of about 21.4 ft^3/s, or about 0.65 $ft^3/s/mi^2$. At this discharge the depth in the deepest portion of the cross section was about 1.14 ft, and the average depth in the section was 0.56 ft. The wetted perimeter was 39.24 ft, or about 95 percent of bankfull wetted perimeter. The limiting R2Cross criterion was the discharge having a mean velocity of 1.0 ft/s.

A wetted perimeter-discharge relation was determined for the cross section with WinXSPRO. Because of the flat streambed across the section, possibly created by channel alterations, low discharges of about 1.3 ft^3/s will wet the channel to the bottom of the bank identified in the field. Depths are extremely shallow at this low discharge value, however, and are below the depth of the top of the cobbles and boulders in the streambed. Breaks in the wetted perimeter-discharge relation occur at a discharge of about 11.4 ft^3/s, or 0.35 $ft^3/s/mi^2$. At this discharge, the depth in the deepest part of the cross section and the average depth of the section were estimated to be 0.98 and 0.41 ft, respectively. The wetted perimeter was estimated to be 38.7 ft, or about 93 percent of bankfull wetted perimeter. The mean velocity for the section was estimated to be 0.75 ft/s. For the R2Cross Method, the average of the streamflow requirements for the two cross sections was 0.59 $ft^3/s/mi^2$. For the Wetted-Perimeter method, the average of the streamflow requirements for the two cross sections was 0.25 $ft^3/s/mi^2$.

Table 1.3. Hydraulic criteria simulated by WinXSPRO for the Usquepaug River at Route 138, downstream section, Richmond/South Kingstown, Rhode Island

[Z, stage; A, area; P, wetted perimeter; W, width; R, hydraulic radius; D, average depth; S, slope; *n*, Manning's n; V, average velocity; Q, discharge; ft, feet; ft^3/s, cubic feet per second; ft^2, square feet]

Condition	Hydraulic parameters									
	Z (ft)	A (ft^2)	P (ft)	W (ft)	R (ft)	D (ft)	S (ft/ft)	n	V (ft/s)	Q (ft^3/s)
Field-identified bottom of bank	0.47	3.07	12.99	12.40	0.24	0.25	0.007	0.108	0.44	1.40
Meets R2Cross wetted-perimeter criterion	.70	6.80	21.36	20.30	.32	.34	.007	.098	.58	3.94
Meets R2Cross average-depth criterion	.93	13.35	35.97	34.45	.37	.39	.007	.088	.71	9.48
Wetted-Perimeter streamflow requirement	.98	15.13	38.73	37.12	.39	.41	.007	.085	.75	11.40
Aquatic-Base-Flow 0.5 $ft^3/s/mi^2$ default flow	1.04	17.37	38.91	37.26	.45	.47	.006	.083	.85	14.73
Stage of calibration discharge (20.6 ft^3/s)	1.11	19.98	39.13	37.42	.51	.53	.006	.800	.96	19.22
Meets R2Cross average-velocity criterion	1.14	21.11	39.24	37.50	.54	.56	.006	.078	1.01	21.35
Stage of calibration discharge (32.9 ft^3/s)	1.33	28.29	39.93	38.02	.71	.74	.006	.070	1.35	38.29
Stage of field-identified bankfull discharge	1.77	45.29	41.49	39.14	1.09	1.16	.006	.050	2.47	112.07

3. Site Q5, Queen River near Dawley Road, Exeter, Rhode Island

The study site is the first riffle downstream of the Dawley Road Bridge. Two cross sections were surveyed in this reach. The upstream section was at the head of the riffle, and the downstream section was about 64 ft downstream, near the tail of the riffle. The streambed is primarily cobbles and small boulders. The channel cross sections are roughly trapezoidal in shape. The stream banks of the upstream section and the left bank of the downstream section are steep or vertical with slightly undercut banks. The bank on the right side of the downstream section is soft sediment and wetland vegetation, possibly related to a recent migration of the channel. There is a large amount of submerged aquatic vegetation throughout the riffle, which could create backwater conditions at low flows (at the same discharge, the stream stage would be higher with vegetation in the channel than without vegetation). This riffle becomes a run at low to moderate flows and may be a marginal site for application of the R2Cross method.

For evaluation purposes, flows were modelled by use of both WinXSPRO and by the U.S. Army Corps of Engineers' River Analysis System (HEC-RAS) (Brunner, 2001). Only the HEC-RAS results are reported. Results from the WinXSPRO model indicated that the water-surface slope at the downstream cross section was greater than that at the upstream cross section; this result indicated that the downstream cross section should be used to determine streamflow requirements. At discharges in the range of those required for habitat protection, however, HEC-RAS output showed the water surface at the downstream section to be higher than the streambed at the upstream section, and also showed the slope of the energy-grade line to be steeper for the upstream cross section than for the downstream cross section. This indicates that the downstream cross section may be in a backwater condition at low discharges, and that the upstream section should be used for the R2Cross and Wetted-Perimeter analysis.

A one-dimensional, steady-flow, water-surface-profile model, HEC-RAS, was used to simulate the water-surface profile at this study site. The shape of the channel and valley were nearly uniform in the area where cross sections were surveyed. Consequently, the downstream cross section was used to make a template for two cross sections downstream of the surveyed area, and surveyed water levels were used to adjust the elevation of the templated cross sections. The upstream cross section and surveyed water surfaces were used to make a template and adjust the elevations of two additional cross sections, one between the surveyed cross sections, and one upstream of the surveyed cross sections. The model was run as subcritical flow, with a downstream water-surface slope of 0.000282 ft/ft as a

boundary condition. Manning's roughness values at the upstream cross section were varied between 0.145 at low flows to 0.05 at a bankfull discharge of 44 ft^3/s. Hydraulic information from the HEC-RAS models was used to determine relations between discharge and other hydraulic parameters used to determine streamflow requirements (table 1.4).

The HEC-RAS model was used to produce a staging table of average depth, average velocity, and percent bankfull wetted perimeter for a range of discharges. The three R2Cross criteria for determining streamflow requirements were an average depth of 0.30 ft, a wetted perimeter of 15.8 ft, and an average velocity of 1.0 ft/s. The limiting R2Cross criterion was the discharge having a mean velocity of 1.0 ft/s. These criteria were determined from the model to be met at a discharge of 33.5 ft^3/s, or about 1.82 $ft^3/s/mi^2$. At this discharge the depth in the deepest portion of the cross section was about 1.47 ft, and the average depth in the section was 1.30 ft. The wetted perimeter was 31.3 ft, or about 99 percent of bankfull wetted perimeter. The R2Cross streamflow requirement determined by HEC-RAS (33.5 ft^3/s) is within about 17 percent of the R2Cross streamflow requirement determined by use of the WinXS Pro models (27.9 ft^3/s).

The elevation of the bottom-of-bank differed by about 0.62 ft between the left and right sides of the channel for the upper cross section. A wetted perimeter-discharge relation was determined for the upper cross section with HEC-RAS. The wetted perimeter-discharge relation has a sharp break in slope that corresponds to stream stage rising over the bottom of the left bank, and a less sharp break in slope that corresponds to stream stage rising over the bottom of the right bank. Because the channel is virtually rectangular in cross section, a very low discharge of about 0.2 ft^3/s corresponds to the sharp break in slope at the bottom of the left bank. A discharge of 3.8 ft^3/s or about (0.21 $ft^3/s/mi^2$) corresponds to the stage equal to the average elevation of the left and right bottom-of-banks. Depths at this discharge are shallow and are about at the top of the cobbles and boulders in the streambed. At this discharge, the water depth in the deepest part of the cross section and the average depth of the section were estimated to be 0.38 and 0.35 ft, respectively. The wetted perimeter was estimated to be 28.14 ft, or about 89 percent of bankfull wetted perimeter. The mean velocity for the section was estimated to be 0.39 ft/s.

Table 1.4. Hydraulic criteria simulated by HEC-RAS for the Queen River near Dawley Road, Exeter, Rhode Island

[Z, stage; A, area; P, wetted perimeter; W, width; R, hydraulic radius; D, average depth; S, slope; *n*, Manning's n; V, average velocity; Q, discharge; ft, feet; ft^3/s, cubic feet per second; ft^2, square feet]

Condition	Hydraulic parameters									
	Z (ft)	A (ft^2)	P (ft)	W (ft)	R (ft)	D (ft)	S (ft/ft)	n	V (ft/s)	Q (ft^3/s)
Meets R2Cross wetted-perimeter criterion	0.12	0.74	15.85	15.84	0.05	0.05	0.000924	0.145	0.04	0.03
Lowest field-identified bottom of bank	.18	2.02	25.55	25.53	.08	.08	.001509	.143	.07	.15
Wetted-Perimeter streamflow requirement	.20	2.36	25.63	25.59	.09	.09	.001573	.142	.08	.20
Meets R2Cross average-depth criterion	.41	8.08	27.51	27.32	.29	.30	.004322	.134	.32	2.60
Average field-identified bottom of banks	.48	9.84	28.14	27.90	.35	.35	.004738	.132	.39	3.80
Aquatic-Base-Flow 0.5 $ft^3/s/mi^2$ default flow	.69	15.57	29.75	29.35	.54	.54	.005238	.123	.58	9.2
Stage of calibration discharge (7.21 ft^3/s)	.73	17.26	30.08	29.64	.57	.58	.005202	.122	.61	10.5
Stage of calibration discharge (15.9 ft^3/s)	.90	22.09	30.46	29.78	.73	.74	.004800	.115	.72	15.9
Meets R2Cross average-velocity criterion	1.28	33.48	31.27	29.95	1.07	1.12	.002432	.077	1.00	33.5
Stage of field-identified bankfull discharge	1.47	39.11	31.67	29.97	1.24	1.30	.001088	.050	1.13	44.0

4. Site Q3, Queen River near William Reynolds Road, Exeter, Rhode Island

Two cross sections were surveyed in the study reach, about 100 ft downstream from William Reynolds Road. The upper cross section is at the head of the riffle, about 15 ft upstream of the downstream cross section. The stream has low undercut banks and a wide flood plain. The channel cross sections are roughly rectangular in shape, and the streambed is primarily gravel and cobble. The upper cross section was used for the R2Cross analysis.

For evaluation purposes, streamflow requirements for habitat protection were determined by use of both WinXSPRO and HEC-RAS models. Water-surface elevations simulated by the HEC-RAS model indicated that the upstream cross section is in backwater from the downstream section for most flows. Because too few cross sections were surveyed to calibrate the HEC-RAS model for the downstream cross section within an acceptable level of confidence, few water surfaces were surveyed between cross sections, and the channel in this reach was too heterogeneous to allow templated cross sections to be added between surveyed cross sections, the HEC-RAS results were not used to determine streamflow requirements at this site, and the WinXSPRO results are reported.

At the downstream section, the water-surface slope was surveyed to be 0.078 ft/ft in the area of the riffle and 0.010 ft/ft for the reach. Manning's equation was used to calculate a roughness of about 0.082 at a discharge of 1.76 ft^3/s. Bankfull elevations were determined in the field during surveying and the roughness at bankfull flow was estimated by means of Barnes (1967) and Hicks and Mason (1991) to be 0.040. Manning's equation was applied with WinXSPro version 2.0 software (U.S. Department of Agriculture, 1998) and calibrated to the measured conditions, to develop stage-discharge relations at the site. The bankfull discharge was estimated to be about 68 ft^3/s. Bankfull channel width and bankful wetted perimeter at the cross section were determined to be 17.5 and 19.4 ft, respectively. Hydraulic parameters simulated by WinXSPRO and used to determine R2Cross and Wetted-Perimeter streamflow requirements are shown in table 1.5.

The three R2Cross criteria for determining streamflow requirements were an average depth of 0.20 ft, a wetted perimeter of 9.68 ft, and an average velocity of 1.0 ft/s. These criteria were determined from the model to be met at a discharge of 6.96 ft^3/s, or about 1.86 $ft^3/s/mi^2$. At this discharge the depth in the deepest portion of the cross section was about 0.74 ft, and the average depth in the section was 0.43 ft. The wetted perimeter was 17.09 ft, or about 88 percent of bankfull wetted perimeter. The limiting R2Cross criterion was the discharge having a mean velocity of 1.0 ft/s.

A wetted perimeter-discharge relation for the cross section was determined with WinXSPRO. Breaks in the wetted perimeter-discharge relation correspond to a fully wetted channel bed at a discharge of about 2.38 ft^3/s, or 0.63 $ft^3/s/mi^2$. At this discharge, the

Table 1.5. Hydraulic criteria simulated by WinXSPRO for the Queen River near William Reynolds Road, Exeter, Rhode Island

[Z, stage; A, area; P, wetted perimeter; W, width; R, hydraulic radius; D, average depth; S, slope; *n*, Manning's n; V, average velocity; Q, discharge; ft, feet; ft^3/s, cubic feet per second; ft^2, square feet]

Condition	Hydraulic parameters									
	Z (ft)	A (ft^2)	P (ft)	W (ft)	R (ft)	D (ft)	S (ft/ft)	n	V (ft/s)	Q (ft^3/s)
Meets R2Cross wetted-perimeter criterion	0.37	1.34	9.75	9.61	0.14	0.14	0.008	0.089	0.4	0.53
Field-identified bottom of bank	.38	1.44	10.16	10.01	.14	.14	.008	.089	.41	.59
Meets R2Cross average-depth criterion	.50	3.06	15.80	15.47	.19	.20	.008	.083	.53	1.63
Stage of calibration discharge (1.76 ft^3/s)	.51	3.21	15.95	15.60	.20	.21	.008	.083	.55	1.77
Aquatic-Base-Flow 0.5 $ft^3/s/mi^2$ default flow	.53	3.53	16.48	16.09	.21	.22	.008	.082	.58	2.05
Wetted-Perimeter streamflow requirement	.55	3.86	16.70	16.28	.23	.24	.008	.081	.62	2.38
Meets R2Cross average-velocity criterion	.74	6.96	17.09	16.36	.41	.43	.008	.073	1.00	6.96
Stage of field-identified bankfull discharge	1.52	19.92	19.36	17.48	1.03	1.14	.008	.040	3.40	67.8

depth in the deepest part of the cross section and the average depth of the section were estimated to be 0.55 and 0.24 ft, respectively. The wetted perimeter was estimated to be 16.7 ft, or about 86 percent of bankfull wetted perimeter. The mean velocity for the section was estimated to be 0.62 ft/s.

5. Site L1, Locke Brook at Mail Road, Exeter, Rhode Island

Two cross sections were surveyed in the study reach, about 600 ft downstream from Mail Road. The downstream cross section was about 25 ft downstream of the upstream cross section. The downstream cross section, which has a steeper slope than the upstream cross section, was selected for R2Cross analysis. The stream has high banks, the channel is incised, and the flood plain is narrow or nonexistent. The channel cross sections are roughly trapezoidal in shape, and the streambed is primarily cobbles, small boulders, and coarse sand.

At the downstream section, the water-surface slope was surveyed to be 0.014 ft/ft in the area of the riffle and 0.009 ft/ft for the reach. Manning's equation was used to calculate a roughness of 0.090 at a discharge of 3.08 ft^3/s. Bankfull elevations were determined in the field during surveying and the roughness at bankfull flow was estimated by means of Barnes (1967) and Hicks and Mason (1991) to be 0.040. To develop stage-discharge relations at the site, Manning's equation was applied with WinXSPro version 2.0 software (U.S. Department of Agriculture, 1998). The model was calibrated to a discharge measurement of 3.08 ft^3/s, to within 0.3 percent error. Bankfull flow at the site was estimated to be about 55 ft^3/s. Bankfull channel width and bankful wetted perimeter at the cross section were determined to be about 19.4 and about 20.2 ft, respectively. Hydraulic parameters simulated by WinXSPRO and used to determine R2Cross and Wetted-Perimeter streamflow requirements are shown in table 1.6.

The three R2Cross criteria for determining streamflow requirements were an average depth of 0.20 ft, a wetted perimeter of 10.1 ft, and an average velocity of 1.0 ft/s. These criteria were determined from the model to be met at a discharge of 5.72 ft^3/s, or about 1.3 $ft^3/s/mi^2$. At this discharge the depth in the deepest portion of the cross section was about 0.66 ft, and the average depth in the section was 0.26 ft. The wetted perimeter was 15.8 ft, or about 78 percent of bankfull wetted perimeter. The limiting R2Cross criterion was the discharge having a mean velocity of 1.0 ft/s.

A wetted perimeter-discharge relation was determined for the cross section with WinXSPRO. Breaks in the wetted perimeter-discharge relation occur at a discharge of about 2.9 ft^3/s, or 0.66 $ft^3/s/mi^2$. At this discharge, the depth in the deepest part of the cross section and the average depth of the section were estimated to be 0.51 and 0.25 ft, respectively. The wetted perimeter was estimated to be about 15.5 ft,

Table 1.6. Hydraulic criteria simulated by WinXSPRO for Locke Brook at Mail Road, Exeter, Rhode Island

[Z, stage; A, area; P, wetted perimeter; W, width; R, hydraulic radius; D, average depth; S, slope; *n*, Manning's n; V, average velocity; Q, discharge; ft, feet; ft^3/s, cubic feet per second; ft^2, square feet]

Condition	Hydraulic parameters									
	Z (ft)	A (ft^2)	P (ft)	W (ft)	R (ft)	D (ft)	S (ft/ft)	n	V (ft/s)	Q (ft^3/s)
Field-identified bottom of bank	0.27	0.83	7.04	6.88	0.12	0.12	0.015	0.109	0.40	0.33
Meets R2Cross wetted-perimeter criterion	.31	1.17	10.56	10.34	.11	.11	.015	.106	.39	.46
Meets R2Cross average-depth criterion	.43	2.67	14.08	13.71	.19	.20	.014	.097	.60	1.61
Aquatic-Base-Flow 0.5 $ft^3/s/mi^2$ default flow	.47	3.24	14.85	14.43	.22	.22	.014	.095	.67	2.18
Wetted-Perimeter streamflow requirement	.51	3.83	15.53	15.06	.25	.25	.014	.092	.75	2.87
Stage of calibration discharge (3.07 ft^3/s)	.09	.77	3.07	15.16	.25	.26	.014	.091	.77	3.07
Meets R2Cross average-velocity criterion	.63	5.71	16.80	16.23	.34	.35	.013	.083	1.00	5.72
Stage of field-identified bankfull discharge	1.24	16.58	20.18	19.37	.82	.86	.010	.040	3.32	54.98

or about 76 percent of bankfull wetted perimeter. The mean velocity for the section was estimated to be 0.73 ft/s.

6. Site F2, Fisherville Brook at Liberty Church Road, Exeter, Rhode Island

Two cross sections were surveyed in this reach. Both cross sections were within the riffle; however, a steeper slope measured for the downstream section and identical elevations for the mean annual high-water line of both cross sections indicate that the downstream section is the controlling section and would be more appropriate for application of R2Cross analysis. The stream has high banks, the channel is incised, and the flood plain is narrow or nonexistent. The channel cross sections are roughly trapezoidal in shape, and the streambed is primarily cobbles, small boulders, and coarse sand.

At the downstream section, the water-surface slope was surveyed to be 0.015 ft/ft in the area of the riffle. Manning's equation was used to calculate a roughness of about 0.090 at a measured discharge of 3.61 ft^3/s. Bankfull elevations were determined in the field during surveying, and the roughness at bankfull flow was estimated by means of Barnes (1967) and Hicks and Mason (1991) to be 0.036. Manning's equation was applied with WinXSPro version 2.0 software (U.S. Department of Agriculture, 1998) and calibrated to the measured conditions to develop stage-discharge relations at the site. Bankfull flow at the site was estimated to be 72.2 ft^3/s. Bankfull channel width and bankful wetted perimeter at the cross section were determined to be 17.46 and 20.01 ft, respectively. Hydraulic parameters simulated by WinXSPRO and used to determine R2Cross and Wetted Perimeter streamflow requirements are shown in table 1.7.

The three R2Cross criteria for determining streamflow requirements were an average depth of 0.20 ft, a wetted perimeter of 10.0 ft, and an average velocity of 1.0 ft/s. These criteria were determined from the model to be met at a discharge of 5.84 ft^3/s, or about 0.73 $ft^3/s/mi^2$. At this discharge the depth in the deepest portion of the cross section was about 0.66 ft, and the average depth in the section was 0.39 ft. The wetted perimeter was 16.77 ft, or about 84 percent of bankfull wetted perimeter. The limiting R2Cross criterion was the discharge having a mean velocity of 1.0 ft/s.

A wetted perimeter-discharge relation was determined for the cross section with WinXSPRO. Breaks in the wetted perimeter-discharge relation correspond to discharge of about 4.1 ft^3/s, or 0.5 $ft^3/s/mi^2$. At this discharge, the depth in the deepest part of the cross section and the average depth of the section were estimated to be 0.59 and 0.32 ft, respectively. The wetted perimeter was estimated to be

Table 1.7. Hydraulic criteria simulated by WinXSPRO for Fisherville Brook at Liberty Church Road, Exeter, Rhode Island

[Z, stage; A, area; P, wetted perimeter; W, width; R, hydraulic radius; D, average depth; S, slope; *n*, Manning's n; V, average velocity; Q, discharge; ft, feet; ft^3/s, cubic feet per second; ft^2, square feet]

Condition	Hydraulic parameters									
	Z (ft)	A (ft^2)	P (ft)	W (ft)	R (ft)	D (ft)	S (ft/ft)	n	V (ft/s)	Q (ft^3/s)
Meets R2Cross wetted-perimeter criterion	0.30	1.03	10.14	9.74	0.10	0.11	0.014	0.106	0.36	0.37
Field-identified bottom of bank	.38	1.92	12.76	12.13	.15	.16	.014	.101	.49	.94
Meets R2Cross average-depth criterion	.45	2.82	14.43	13.59	.20	.21	.014	.097	.61	1.71
Stage of calibration discharge (3.61 ft^3/s)	.55	4.26	16.01	14.90	.27	.29	.013	.090	.78	3.33
Aquatic-Base-Flow 0.5 $ft^3/s/mi^2$ default flow	.59	4.86	16.45	15.24	.30	.32	.013	.088	.86	4.18
Wetted-Perimeter streamflow requirement	.59	4.86	16.45	15.24	.30	.32	.013	.088	.86	4.18
Meets R2Cross average-velocity criterion	.66	5.93	16.77	15.39	.35	.39	.013	.083	1.01	5.98
Stage of field-identified bankfull discharge	1.42	18.57	20.01	17.46	.93	1.06	.010	.036	3.89	72.22

16.4 ft, or about 94 percent of bankfull wetted perimeter. The mean velocity for the section was estimated to be 0.86 ft/s.

7. Site F1, Fisherville Brook near Pardon Joslin Road, Exeter, Rhode Island

Two cross sections were surveyed in the study reach about 300 ft downstream from a small dam on Fisherville Brook. The upper cross section is at the head of a riffle, about 20 ft upstream of the downstream cross section. The stream in this reach is a series of small riffles. The upstream cross section was selected for R2Cross analysis because it is a hydraulic control. The downstream section, surveyed to calculate slope, was determined to be in backwater at low to moderate flows; therefore, it was not used in the analysis.

At the upstream section, the water-surface slope was surveyed to be 0.011 ft/ft in the area of the riffle. Manning's equation was used to calculate a roughness of about 0.055 at a discharge of 1.24 ft^3/s. Bankfull elevations were determined in the field during surveying, and the roughness at bankfull flow was estimated by means of Barnes (1967) and Hicks and Mason (1991) to be 0.035. Manning's equation was applied with WinXSPro version 2.0 software (U.S. Department of Agriculture, 1998) and calibrated to the measured conditions, to develop stage-discharge relations at the site. Bankfull discharge at the site was estimated to be about 20.7 ft^3/s. Bankfull channel width and bankful wetted perimeter at the cross section were determined to be about 15.3 and 15.8 ft, respectively. Hydraulic parameters simulated by WinXSPRO and used to determine R2Cross and Wetted-Perimeter streamflow requirements are shown in table 1.8.

The three R2Cross criteria for determining streamflow requirements were an average depth of 0.20 ft, a wetted perimeter of 7.90 ft, and an average velocity of 1.0 ft/s. These criteria were determined from the model to be met at a discharge of 2.46 ft^3/s, or about 0.58 $ft^3/s/mi^2$. At this discharge, the depth in the deepest portion of the cross section was about 0.35 ft, and the average depth in the section was 0.22 ft. The wetted perimeter was 11.7 ft, or about 74 percent of bankfull wetted perimeter. The limiting R2Cross criterion was the discharge having a mean velocity of 1.0 ft/s.

A wetted perimeter-discharge relation was determined for the cross section with WinXSPRO. Breaks in the wetted perimeter-discharge relation occur at a discharge of about 1.38 ft^3/s, or 0.33 $ft^3/s/mi^2$. At this discharge, the depth in the deepest part of the cross section and the average depth of the section were estimated to be 0.28 and 0.15 ft, respectively. The wetted perimeter was estimated to be about 11.1 ft, or about 70 percent of bankfull wetted perimeter. The mean velocity at the wetted-perimeter flow requirement was estimated to be 0.81 ft/s.

Table 1.8. Hydraulic criteria simulated by WinXSPRO for Fisherville Brook near Pardon Joslin Road, Exeter, Rhode Island

[Z, stage; A, area; P, wetted perimeter; W, width; R, hydraulic radius; D, average depth; S, slope; *n*, Manning's n; V, average velocity; Q, discharge; ft, feet; ft^2, square feet; ft^3/s, cubic feet per second]

Condition	Hydraulic parameters									
	Z (ft)	A (ft^2)	P (ft)	W (ft)	R (ft)	D (ft)	S (ft/ft)	n	V (ft/s)	Q (ft^3/s)
Meets R2Cross wetted-perimeter criterion	0.16	0.57	7.90	7.89	0.07	0.07	0.012	0.058	0.48	0.28
Stage of calibration discharge (1.24 ft^3/s)	.27	1.60	10.98	10.95	.15	.15	.011	.055	.78	1.24
Field-identified bottom of bank	.27	1.60	10.98	10.95	.15	.15	.011	.055	.78	1.24
Wetted-Perimeter streamflow requirement	.28	1.71	11.09	11.06	.15	.15	.011	.055	.81	1.38
Aquatic-Base-Flow 0.5 $ft^3/s/mi^2$ default flow	.32	2.16	11.44	11.38	.19	.19	.100	.540	.92	1.99
Meets R2Cross average-depth criterion	.33	2.27	11.53	11.46	.20	.20	.010	.053	.95	2.16
Meets R2Cross average-velocity criterion	.35	2.50	11.70	11.62	.21	.22	.010	.053	1.01	2.52
Stage of field-identified bankfull discharge	.94	10.55	15.81	15.31	.67	.69	.004	.035	1.96	20.66